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POLAR ENERGY RESOURCES POTENTIAL

REPORT

PREPARED FOR THE

SUBCOMMITTEE ON ENERGY RESEARCH,
DEVELOPMENT AND DEMONSTRATION,

AND THE

SUBCOMMITTEE ON ENERGY RESEARCH,
DEVELOPMENT AND DEMONSTRATION
(Fossil Fuels)

OF THE

COMMITTEE ON SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES
NINETY-FOURTH CONGRESS
SECOND SESSION

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LETTER OF TRANSMITTAL

Committee on Science and Technology,
U.S. House of Representatives,
Washington, D.C., August 10, 1976.

Hon. Olin E. Teague,
Chairman, Committee on Science and Technology, U.S. House of Representatives, Washington, D.C.

Dear Mr. Chairman: Since our Nation's supply of energy from domestic sources becomes more depleted each year, we need to inventory all available energy resources including those in the polar regions and particularly in the Arctic regions. These regions represent a major area of potential resources which have only been analyzed on a limited basis in the past.

We are pleased to submit the following comprehensive report entitled, "Polar Energy Resources Potential", which was prepared by the Congressional Research Service of the Library of Congress at our request. It will serve as an important document for the Members of the Committee on Science and Technology and for the Congress as we attempt to set forth a policy of alternatives related to the development of energy resources to meet the Nation's and the world's energy needs.

Sincerely,

Ken Hechler,
Chairman, Subcommittee on Energy Research, Development and Demonstration (Fossil Fuels).

Alphonzo Bell,
Ranking Minority Member, Subcommittee on Energy Research, Development and Demonstration (Fossil Fuels).

Mike McCormack,
Chairman, Subcommittee on Energy Research, Development and Demonstration.

Barry M. Goldwater, Jr.,
Ranking Minority Member, Subcommittee on Energy Research, Development and Demonstration.

LETTER OF SUBMITTAL

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Washington, D.C.

Hon. KEN HECHLER, *Chairman.*

Hon. ALPHONZO BELL, *Ranking Minority Member, Subcommittee on Energy Research, Development, and Demonstration (Fossil Fuels).*

Hon. MIKE MCCORMACK, *Chairman.*

Hon. BARRY M. GOLDWATER, JR., *Ranking Minority Member, Subcommittee on Energy, Research, Development, and Demonstration, Committee on Science and Technology, U.S. House of Representatives, Washington, D.C.*

DEAR CONGRESSMEN HECHLER, BELL, MCCORMACK, GOLDWATER, SYMINGTON, AND MOSHER: In response to your request I am submitting a comprehensive report on polar energy resources potential.

The study covers both Antarctic and Arctic energy resources including coal, oil, natural gas, hydroelectric power, geothermal energy, oil shale, uranium, solar energy, and wind power. The environment, geology, topography, climate, and weather are also treated. Consideration is given to the international relations involved in energy resource exploitation in both polar regions and the technologies necessary to develop polar resources are discussed.

The report was prepared by Mr. Joseph P. Riva, Jr., Specialist in Earth Sciences, and Dr. James E. Mielke, Analyst in Marine and Earth Sciences, both of the Science Policy Research Division. Mr. Riva wrote the chapters concerning oil, gas, and geothermal energy, while Dr. Mielke prepared the sections dealing with coal, hydroelectric power, oil shale, uranium, the environment, and international relations.

We hope that this report will serve your committee's needs as well as those of other committees and Members of Congress concerned with the development of the vast energy resources contained in the polar regions.

Yours sincerely,

NORMAN BECKMAN,
Acting Director.

LETTER REQUESTING STUDY

COMMITTEE ON SCIENCE AND TECHNOLOGY,
U.S. HOUSE OF REPRESENTATIVES,
Washington, D.C., May 9, 1975.

Mr. GEORGE A. DOUMANI,
Science Policy Research Division, Congressional Research Service,
The Library of Congress, Washington, D.C.

DEAR GEORGE: The Subcommittees on Energy Research, Development, and Demonstration, Energy Research, Development and Demonstration (Fossil Fuels) and Science, Research and Technology have a broad interest in basic research, new energy technologies, and issues affecting them. As demands for energy increase, a more careful look is being taken at the resources of our polar regions. Because of potential legislative interest in the R & D aspects of utilizing these resources, as well as our responsibility for the current NSF research activities in the polar regions, we would appreciate it if your section could undertake a study of the energy resource potential of the polar regions.

The study should cover both Antarctic and Arctic energy resources including (but not limited to) oil, natural gas, coal, uranium, hydroelectric, and geothermal energy. It would be appropriate to concentrate on the technologies necessary to develop polar resources, and discuss the basic facts and general aspects of the polar energy resource potential. Another section might be devoted to international agreements and possible conflicts which might bear on, or result from, polar resource development. Of prime concern also is protection of existing scientific programs.

For further information and details concerning this request, please contact Dr. Tom Ratchford of the Committee Staff.

Sincerely yours,

KEN HECHLER,
ALPHONZO BELL,
MIKE MCCORMACK,
BARRY M. GOLDWATER, Jr.

CONTENTS

Page
Letter of Transmittal ---- III
Letter of Submittal ---- V
Letter Requesting Study ---- VII
Abstract ---- XV

Part I. Antarctic (south of 60 degrees)

Introduction ---- 1
Environment and terrain ---- 3
  Climate and weather ---- 3
  Topography ---- 4
  Geology ---- 5
  Environmental considerations of resource development ---- 6
Antarctic energy resources ---- 9
  Coal ---- 9
  Oil and natural gas ---- 10
    Potential resources ---- 10
    Technology ---- 13
  Geothermal energy ---- 14
Other energy resources ---- 16
  Uranium ---- 16
  Solar ---- 16
International relations ---- 17
  Early discoveries and claims ---- 17
  The International Geophysical Year ---- 20
  The Antarctic Treaty ---- 21
Summary ---- 25

Part II. Arctic (north of 60 degrees)

Introduction ---- 27
Environment and terrain ---- 29
  Climate and weather ---- 29
  Ocean areas ---- 30
    The Arctic Ocean ---- 30
    Other Arctic Seas ---- 31
  Land areas ---- 32
    Topography ---- 32
    Geology ---- 34
    Environmental considerations of resource development ---- 34
Coal ---- 39
  Alaska ---- 39
    History of coal development in Alaska ---- 39
    Resource potential ---- 40
    Reserves ---- 41
    Coal mining problems in Alaska ---- 41
    Coal leases and prospecting permits in Alaska ---- 42
    Ship transportation of Alaskan coal ---- 43
    Land transportation of Alaskan coal ---- 46
    Future prospects for Alaskan coal ---- 49
    Gasification or liquefaction of coal from the North Slope ---- 50
  Arctic Canada ---- 51
  Greenland ---- 51
  Norway (including Svalbard) ---- 51
  Sweden ---- 52
  Finland ---- 52
  Arctic Russia ---- 53
    Resources, reserves, and production ---- 53
    Soviet mining technology ---- 56
    Future prospects for coal from Arctic Russia ---- 60
    Soviet coal gasification ---- 60

Page
Oil and natural gas 63
  Alaska 63
    Introduction 63
    Alaska Peninsula—Cook Inlet Province 63
    Nushagak Lowland and Bristol Bay Tertiary Province 67
    Bering Sea Shelf Province 68
    Pacific-margin Tertiary Province 69
    Yukon-Koyukuk Province 72
    Arctic Slope Province 72
    Yukon—Porcupine Province 78
    Alaskan oil and gas reserve estimates 78
    Arctic exploration and drilling technology 80
    Arctic pipeline transportation technology 83
    Gas pipeline proposals 84
    Tanker transportation proposals 86
    Other transportation proposals 89
  Arctic Canada 90
    Introduction 90
    The Mackenzie Delta 91
    The Beaufort Sea 94
    The Arctic Islands 96
    The Labrador Shelf 101
    Canadian oil policy 102
  Greenland 104
  Norway 105
  Sweden 109
  Arctic Russia 109
    Introduction 109
    West Siberian Basin Oil 112
    West Siberian Basin Gas 119
    Pechora Basin 123
    East Siberian Province 124
    East Siberian and Chukchi Seas 125
    Anadyr' Basin 125
    Future development 125
  Summary and comparisons 131
Hydroelectric Power 135
  Alaska 135
    Resources and early development 135
    Hydroelectric development by the Federal Government 137
    Considerations for future development 137
    Tidal power 137
  Arctic Canada 138
  Greenland 138
  Iceland 139
  Norway 139
  Sweden 139
  Finland 140
  Arctic Russia 140
    Resource potential and generation capacity 140
    Tidal power development and technology 142
Geothermal energy 145
  Introduction 145
  North American Arctic and Greenland 146
  Iceland 147
  Norway, Sweden, and Finland 149
  Arctic Russia 149
  Summary and comparisons 151
Other energy resources 153
  Oil shale 153
    Alaska 153
    Arctic Canada 153
    Sweden 154
    Arctic Russia 154

Other energy resources—Continued

Page

- Uranium 156
  - Alaska 156
  - Arctic Canada 156
  - Greenland 157
  - Norway 157
  - Sweden 157
  - Finland 158
  - Arctic Russia 158
- Solar energy 159
  - Solar 159
  - Wind 160

International relations 161
- Land areas 161
- Ocean areas and U.N. Law of the Sea Conferences 161
- The sector principle 162
- Continental Shelf boundary dispute between Norway and the Soviet Union 163
- Other Continental Shelf boundary disputes 164

Summary 165

Appendix I 171

POLAR ENERGY RESOURCES POTENTIAL

By Joseph P. Riva, Jr.

and

James E. Mielke

ABSTRACT

The Polar regions have for several decades been subject to systematic geological exploration and the Arctic, in particular, has been found to contain vast energy resources. The exploitation of some of these energy resources on a large scale, however, is a recent undertaking that was prompted by the increasing depletion of oil and gas deposits in some of the temperate regions.

Very large scale exploitation of Arctic oil and gas is underway in the Soviet Union which overtook the United States to become the world's leading oil producer in 1974. About 95 percent of the U.S.S.R. net oil production gain in that year came from Western Siberia. The Soviet Arctic contains vast oil and natural gas deposits with known oil reserves of 88.5 billion barrels and known gas reserves of 1,004 to 1,284 trillion cubic feet. The Soviet Government is committed to the rapid development of the immense potential of its Arctic oil and gas resources.

The United States also has a large Arctic oil and gas potential in the State of Alaska. Known oil reserves in this region are listed as 10.107 billion barrels and known gas reserves have been put at 31.867 trillion cubic feet. The U.S. is exercising caution in its development of these reserves, however, because of environmental considerations.

Arctic Canada contains known gas reserves of between 21.2 and 27.9 trillion cubic feet with a large potential for additional gas and oil discoveries. The Canadian Government has adopted a policy of self-reliance in oil and gas in order to reduce dependence on imported oil. The policy includes increasing the development of the Arctic areas. An indication of this policy was the recent Canadian decision to allow exploratory drilling in the Beaufort Sea despite opposition from environmental groups and from the U.S. Government.

Drilling will also be undertaken on the Norwegian shelf in the northern sections of the North Sea. The Government of Norway has chosen the two most promising areas and has indicated that concessions will be granted in time for drilling in 1977.

Known Arctic oil reserves are almost three times greater than those of the United States and the natural gas reserves of the Arctic are even more significant, almost equaling the total gas reserves of the entire non-Communist world. It is apparent that Arctic oil and gas exploration and exploitation will be accelerated, particularly in the Soviet Union and Canada and thus, the technology of polar oil and gas operations can be expected to undergo continuing research and development.

Several estimates have been made of the potential oil and gas resources in Arctic regions. The techniques used to estimate the amount of oil and gas that may be discovered and produced in Alaska are much more conservative (and probably more accurate) than those used to estimate the undiscovered resources of Norway and the Soviet Union, and even of Canada. The known deposits in the Soviet Union

also have a slightly different definition that tends to inflate Soviet reserve figures. In spite of these differences, however, Arctic hydrocarbon resources remain immense, but the greatest amounts are apparently located outside of the United States.

Coal is found in many parts of Alaska, ranging from small occurrences to very extensive fields. The Alaskan coal resource has been conservatively estimated at more than 130 billion tons, with an estimated one-half being recoverable by present mining methods. The ultimate exploitation of these immense deposits will depend upon the development of markets to which transportation costs will be competitive with other sources of supply.

Coal is not presently included among the economically significant energy resources of Arctic Canada, although a large deposit is known in the northwest near the Arctic coast. The shield areas of the Canadian Arctic, Greenland, and Scandinavia are not geologically favorable for coal formation; however, minor deposits have been mined in sedimentary basins in Greenland and Scandinavia and coal is being produced from Spitzbergen by both Russians and Norwegians. The coal resources of the Soviet Arctic are estimated at 3,715 billion tons (about equal to those of the entire United States). Economically minable reserves, however, are estimated at 24 billion tons, most of which is in the European Russian Arctic. The heating capacity of remaining European Russian coal resources is of a low level whereas the largest resources of high quality or coking coal are in inaccessible and inhospitable Siberian regions far from major consuming centers making development and transportation problems immense. As with oil and gas, the Soviets are seeking technology and financing from the West to develop their Siberian coal deposits.

Most Arctic areas have large undeveloped hydroelectric power potential. Alaska contains about one-fourth of the total potential hydroelectric power resources of the United States, but less than one-third of one percent of Alaska's potential hydroelectric power resources have been developed. Arctic Canada and Iceland also have large undeveloped hydroelectric power resources. The Scandinavian countries, on the other hand, have placed greater emphasis on developing their hydroelectric power resources as they have, in the past, lacked other energy sources. Approximately one-half of the hydroelectric power resources of Sweden are being utilized and hydroelectric power is one of the main sources of energy for Finland.

Although the hydroelectric power potential of the northward flowing rivers in the Soviet Arctic is immense, most of the resource potential is downstream near the Arctic Ocean far from where the power would be needed. Environmental concerns have contributed to the postponement of ambitious plans to develop Arctic hydroelectric power which would lead to flooding vast lowland areas of the Arctic. Consequently, there has been relatively little hydroelectric development in the Soviet Arctic with the exception of the Kola Peninsula, the White Sea region, and for local use in mining areas such as Norilsk and Aykhal. Soviet hydroelectric turbogenerators are competitive in Western markets. The Soviet Union also has a tidal power plant in operation in the Arctic.

Alaska has good geological potential for geothermal development in the Aleutian Chain and the Seward Peninsula. Arctic Canada, Greenland, and the Scandinavian countries appear to have little geological potential for geothermal energy exploitation. Iceland, however, is located on the volcanically active mid-Atlantic ridge and has long utilized geothermal energy for space heating and horticulture. Reykjavik, the capital, is almost totally heated by geothermal waters at a cost estimated to be a fraction of fuel oil heating costs. Icelandic geothermal waters are also used to generate electrical power for various industrial purposes. The Government of Iceland plans continued expansion of its considerable current utilization of geothermal energy.

The Soviet Union is the world's leader in the use of geothermal energy for heating purposes. Geothermal waters are also used for horticulture, the generation of electricity, for refrigeration, for thawing frozen soils, and for warming swimming pools and hot baths. In the U.S.S.R., the total consumption of geothermal energy for space heating alone is believed to be the equivalent of the combustion of one million tons of fossil fuel per year. There is great potential for geothermal development in the Soviet Arctic. Western Siberia contains one of the world's largest reservoirs of hot water extending over an area estimated to be about three million square kilometers. There are future plans for the development of electric powers from the Siberian geothermal resource. At the present time, geothermal resource development is actively being pursued by the Soviet Government.

There are no known commercial energy resources in Antarctica. The most promising potential energy resources for future development are apparently petroleum and natural gas, but there are no indications that a large hydrocarbon resource actually exists. The most favorable environment for such a potential resource would be in the sediments of the continental shelf. It has been estimated that this potential could be on the order of 15 billion barrels of oil. Recovery of oil and gas offshore from the Antarctic continent will present great technological and logistical problems. However, the petroleum industry is currently conducting research on drilling and production systems for the ice-prone offshore areas of the Arctic which, if developed, could possibly be transferred with modifications to the Antarctic. It is unlikely that existing coal could be economically exploited in the near future; and unless high grade uranium ore is discovered in quantity, it is unlikely that any other Antarctic energy resources will be exploited for other than local use.

Of the vast known resources contained in the Arctic, only the oil and gas deposits are undergoing, and are expected to continue to undergo, large scale exploitation. This activity will provide incentives for continued development and refinement of polar oil and gas exploration, production, and transportation technology. Other polar energy resources such as coal, hyropower, uranium, and geothermal energy while often present in enormous quantity, will for the near term, be utilized only locally and on a small scale. Ultimate utilization of polar energy resources will be determined by the economic and energy supply conditions in temperate areas and by the degree of success of the technological advancement needed to develop resources in such remote and inhospitable regions.

Photo by James E. Mielke

United States Range, Ellesmere Island, N.W.T., Canada, Rugged mountain beauty typifies some of the coastal areas in the polar regions. Preservation of the polar environment is a major concern with regard to potential resource development.

PART I. ANTARCTIC (SOUTH OF 60 DEGREES)

INTRODUCTION

When the Antarctic Treaty was signed in 1959, there was general agreement that there was no immediate need to include provisions relating to mineral exploitation. Dr. Lawrence M. Gould, who had been chief scientist on the first Byrd expedition in 1928–1930, spoke for most of the scientific community in 1960 when he stated that on the basis of information then available, he would not "give a nickel" for all the mineral resources in Antarctica.[1] However, as a result of increasing technological developments, continued scientific research in polar regions, and the need to develop additional sources of energy, the energy resource potentials of the polar regions are receiving new attention. In view of this concern, parties to the Antarctic Treaty have initiated discussion of possible resource exploitation in Antarctica as it might affect the Antarctic Treaty. At present there are still no known mineral resources in Antarctica that are economically worth developing with the possible exception of icebergs.

The location and development of energy resources in polar regions is hampered by the severe physical and environmental conditions. Although conditions are generally inhospitable to resource development, there are many contrasts between the poles. Much of Antarctica is covered by a thick ice cap. The northern polar region is characterized by continental land masses and numerous islands surrounding the Arctic Ocean.

The Arctic Ocean has an average depth of 2,000 meters and a maximum depth of over 5,000 meters whereas at the South Pole there is a continent rising above sea level to an average height of 2,000 meters with a maximum height of more than 5,000 meters surrounded by ocean. Contrasts in temperatures of the polar regions are also marked (Table 1). With the exception of the Greenland ice cap, mean summer temperatures in the Arctic land areas are above freezing. The opposite is true in the Antarctic where no continental stations have mean summer temperatures above freezing. The Arctic summer thaws produce floods, lakes, bogs, and difficult conditions for land transportation. On the other hand. in several locations. Arctic winters are more severe than those in some of the ice-free areas of Antarctica, e.g. compare Dawson, Canada with McMurdo, Antarctica.

The problem of logistics is common to both polar regions. Consuming areas are far from energy resource location or likely potential resource locations and the costs of transportation are high. The Arctic is somewhat better off in this regard as year round accessibility is possible to all areas of mineral activity. In practice, transportation in winter over frozen roads is preferred to summer land haulage in much of Alaska, Canada, and Siberia. Bulk transport of oil and gas by pipeline is possible over continental areas. Bulk transport by ship is possible year-around in some areas of the Arctic and with icebreaker support only during the summer in other areas.

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[1] Congressional Record, vol. 106, part 12, 86th Congress, 2nd session, 1960, p. 15981.

In the Antarctic, the only means of transporting an energy resource to a population center is by ship or aircraft. Ship transport with the aid of icebreakers is limited to the summer months. Air transport is expensive and would not likely be used for bulk transport of materials unless they were of very high valve. Furthermore, severe storms can prevent air transport to some interior areas for several months during the winter. In general. distances from Antarctic to Southern Hemisphere continents are reasonable, however, shipping from Antarctica to Northern Hemisphere markets, such as the United States, would likely be less economic than utilization of the Arctic resources in the Northern Hemisphere.

Photo by James E. Mielke

C–130 Hercules (Lockheed United States) landing on gravel strip at Alert, Ellesmere Island, N.W.T., Canada. Except for a short summer season when ice conditions allow ship transport to coastal locations, most supply of Arctic bases must be done by aircraft. The National Science Foundation operates five ski equipped Hercules in Antarctica.

TABLE 1.—TEMPERATURES AT SELECTED POLAR LOCATIONS

[In degrees Fahrenheit]

Location and latitude	Summer: 3 mo mean [1]	Winter: 3 mo mean [2]	Maximum	Minimum
Nenana, Alaska, 64°33′ N	+57	−6	+99	−65
Dawson, Yukon, Canada, 64°4′ N	+57	−17	+95	−72
Eureka (Ellesmere Island) NWT, Canada, 79°59′ N	+41	−35	+66	−63
Kiruna, Sweden, 67°49′ N	+52	+10	+84	−29
Eismette (ice cap) Greenland, 70°53′ N	+3	−44	+27	−85
McMurdo (coast), Antarctica, 79°50′ S	+21	−13	+41	−58
Byrd Station (ice cap), Antarctica, 80° S	0	−31	+30	−83

[1] Arctic: June, July, and August; Antarctic: December, January, and February.
[2] Arctic: December, January, and February; Antarctic: June, July, and August.

ENVIRONMENT AND TERRAIN

The continent of Antarctica has an area of 13.2 million square kilometers (5.1 million square miles), approximately equal to one tenth of the earth's land surface. Located at the South Pole, Antarctica is the fifth largest continent, larger than the United States and Mexico combined. Approximately 98 percent of its area is covered by ice that has an average thickness of over a mile. The ice extends 4.5 kilometers (2.8 miles) deep at its thickest and totals about 30 million cubic kilometers (7.2 million cubic miles). It is estimated that over 90 percent of the world's fresh water is in the form of ice and snow in Antarctica, the results of accumulation over millions of years. If all the ice should melt, the oceans would rise between 60 and 90 meters (200 and 300 feet).

Climate and Weather

It is probably an understatement to say that Antarctica is cold. The world's lowest temperature, minus 88° C (−127° F), was recorded in 1960 by Russian scientists at Vostok (Fig. 1) high on the polar plateau. The average coldest-month temperature in the interior is minus 70° C (−94° F). Excluding the Antarctic Peninsula where the climate is relatively mild, the highest temperature recorded in Antarctica was 9° C (48° F) at Casey on the east coast. During the Antarctic summer from December through March, temperatures along the coast may rise above freezing, but inland temperatures remain much colder. In the winter when the sun withdraws, temperatures drop far below zero.

One of the more striking features of Antarctic weather is the strong steady katabatic winds along the coasts. These winds flowing down off the polar plateau are roughly proportional in strength to the steepness of the slope. For a moderate slope a typical wind speed is 20 knots. In the interior of the continent, milder katabatic winds create sastrugi or large rippled snowdrift patterns. Offshore, the strong wind off the continent meets the prevailing easterlies of the Southern Hemisphere making the seas around Antarctica the roughest in the world.

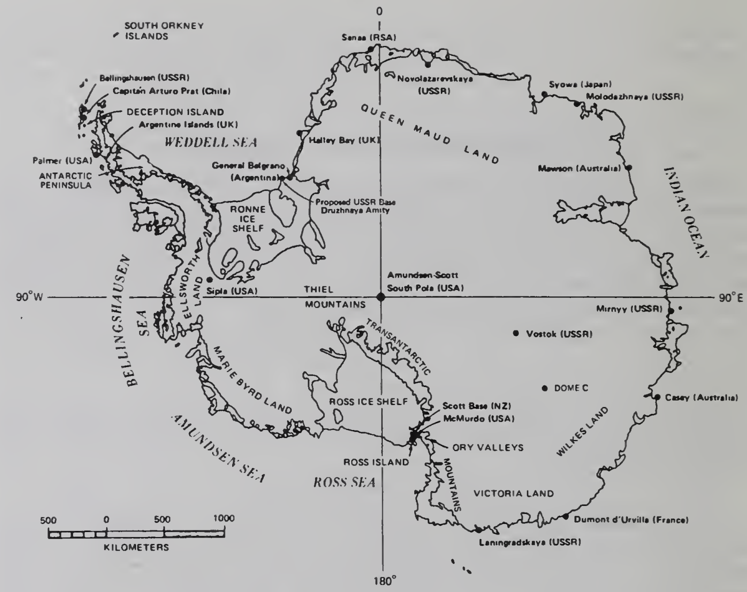

FIGURE 1.—Antarctica: Selected stations and physical features.
Source: National Science Foundation.

Precipitation in most of the Antarctic is very light. Annual snowfall at the South Pole is less than an inch water equivalent, making it drier than some desert areas elsewhere in the world. The great Antarctic blizzards, of which much has been written, consist mostly of snow being blown from one place to another, without additional snowfall. These blizzards occur when the normally smooth flowing katabatic winds reach a critical velocity characterized by strong gusts sometimes exceeding 200 miles per hour at the coast. The localized blizzards occur suddenly and are often only a few hundred meters in height with clear skies above.

TOPOGRAPHY

The continent of Antarctica can be divided into East Antarctica and West Antarctica separated by the wide mountainous belt of the Transantarctic Mountains. The line of division corresponds roughly to the division between the Eastern and Western Hemispheres or more closely to the 30° W–150° E meridian. East Antarctica is roughly twice as large as West Antarctica and is geologically older. It is a vast ice-covered plain with mountain peaks and ice-free areas only around the edges. Under the ice cap there are completely ice-covered mountain chains.

West Antarctica is more mountainous, containing small ranges and isolated peaks, called nunataks, that extend through the ice and snow cover. In a few places ice free areas are found as "dry valleys" where receding glaciers and the arid climate have left morains and brackish lakes on the valley floors. If the present ice cover were removed, West

Antarctica would appear as a series of scattered islands, or group of islands, surrounding the submerged Byrd Basin, which would connect with the Ross Sea, the Amundsen Sea and the Weddell Sea.

The Transantarctic Mountains form a great snow-capped orographic chain that transects the continent and rises from 2000 to 4000 meters in elevation. The mountain chain is reasonably well exposed along its 4000 kilometers of length.

At several places around the coast ice shelves have formed. These are attached to land and extend out into the sea where the outer edges are afloat. The ice shelves may reach several hundred feet in thickness and produce large tabular icebergs when they calve off. Tabular icebergs of more than 100 square miles in area have been reported and are often called ice islands. Some have been sighted as far from Antarctica as 35° S. Glaciers flow down to the coast from the central ice sheet and produce irregular shaped icebergs.

GEOLOGY

The oldest rocks in the continent are found in East Antarctica, which consists of a Precambrian shield of high-grade metamorphic and igneous rocks thought to be related to the African, Indian, and Australian shields. Westward, overlying the shield in part, are a series of essentially undeformed sediments of Paleozoic and early Mesozoic ages (Beacon rocks and their equivalents). The Transantarctic Mountains combine features of the shield with those of younger belts, being formed when Precambrian and Lower Paleozoic rocks were deformed and intruded by large granitic bodies during the Paleozoic Ross orogeny. The general geologic picture is one of gradual addition to the East Antarctic shield toward West Antarctica coupled with orogeny, followed by extensive planation and deposition of continental sediments in middle and late Paleozoic time.

The Ellsworth orogen, the area of West Antarctica between the Ross Sea and the Weddell Sea, is largely ice covered, and the bedrock is largely below sea level. Where exposed, the rocks are Paleozoic sedimentary rocks and Mesozoic intrusions.

The Antarctic Peninsula and the adjacent islands of the Scotia Arc are clearly the continuation of the Andean zone of South America and, together with Ellsworth Land and Marie Byrd Land, form the southern margin of the circum-Pacific belt that has been geologically active to the present time. This tectonic activity contrasts with East Antarctica and the Transantarctic Mountains, which have been inactive (except for some vertical movement and faulting) since Precambrian and early Mesozoic time, respectively.

While the rocks on the continent itself are generally not considered good prospects for hydrocarbon accumulation, younger sediments offshore may be possible source beds and reservoir beds. Tertiary sediments reaching more than 2000 meters in thickness in some locations are found on the continental shelf. The continental shelf is most extensive in the vicinity of the Ross and Weddell Seas. In general the Antarctic continental shelf is found below much deeper water than other shelf areas in the world because of its isostatic depression due to the weight of the Antarctic ice sheet.

ENVIRONMENTAL CONSIDERATIONS OF RESOURCE DEVELOPMENT

There is no commercial development of mineral resources in Antarctica at the present time. Energy resources of potential economic attractiveness could possibly be discovered and developed in the future, but this would depend on advances in technology and higher world values for these resources than presently exist. However, hypothesizing that some energy resources are eventually developed in Antarctica, several statements and assumptions can be made concerning the probable environmental impacts.

The Antarctic ecosystem is sensitive to disturbance and recovery from damage would likely be slow. However, experts generally agree that the present level of scientific activity in Antarctica, including geophysical exploration and geological drilling is unlikely to cause appreciable environmental damage. If resource recovery were to occur, presumably it would be required to comply with reasonable environmental guidelines.

Subsurface drilling may cause local disturbances and the parties conducting scientific drilling are taking precautions to prevent contamination insofar as possible. Scientific drilling is generally conducted in areas unlikely to contain oil and gas. Commercial drilling for oil and gas would utilize elaborate methods to prevent oil and gas pollution.

Offshore technology in the oil and gas industry is rapidly advancing, but as yet there is no adequate technology for oil and gas recovery in some areas of Antarctica, particularly offshore in depths where icebergs may ground on the sea bottom. Icebergs may average 100,000 tons in weight and extend 120 to 150 meters (400 to 500 feet) below sea level. Icebergs of this size could gouge 12 meters (40 feet) deep or more into the bottom sediments.

While icebergs would mainly affect offshore oil and gas operations, they would also be a hazard to any shipping related to resource development; and a collision could release pollutants into the ocean. Marine transportation itself would not be likely to have a serious impact on the marine ecosystem even though the shipping would be concentrated at a few points, the total volume would not likely be great. However, if a large quantity of petroleum were released into the marine environment, a significant adverse impact would result. While it is not possible as yet to predict the duration of this potential impact, it would undoubtedly be longer than a few months but certainly would not be permanent.

In a symposium on Antarctic resources at Polhogda. Norway in May–June 1973, the Technical and Scientific Working Group of the twelve countries which are Consultative Parties to the Antarctic Treaty was of the opinion that field research on the environmental effects of oil pollution in cold ice covered seas is at an early state of development and requires research into the effect of actual cases. Furthermore, the results of research programs on oil pollution in connection with Arctic oil developments were considered unlikely to be of considerable assistance in reducing Antarctic field studies to a minimum because of the large dissimilarities in the two regions.[1] Despite the fact that the *Glomar Challenger* has drilled four holes in the ice-infested Ross Sea, the Working Group felt that a great deal more research would be required before it could be determined what threats Antarctic sea ice conditions and the movement and grounding of large icebergs might pose to any Antarctic offshore oil or gas developments. However, they did point out that technological development in oil spill containment and control has been rapid and will likely be much further improved before any possible oil fields are discovered in the Antarctic.

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[1] Antarctic Resources—Report from the meeting of experts at the Fridtjof Nansen Foundation at Polhogda. May 30–June 10, 1973. In U.S. Congress. Senate. Committee on Foreign Relations. Subcommittee on Oceans and International Environment. Hearing. U.S. Antarctic Policy. Executive hearing held May 15, 1975; made public July 6, 1975. U.S. Government Printing Office, Washington, 1975, p. 73.

Adverse environmental impacts onshore would be localized in the resource areas being developed. Because of the limitations posed by the permanent ice cover, the areas of possible mineral recovery are mainly dispersed around the coast and represent a very small fraction of the total land area. Unless potential energy resource extraction and possibly even on site processing become extensive, the onshore impacts would likely have a negligible effect on the general environment of Antarctica. In the Antarctic there are very few activities contributing to the degradation of air and water quality. Most of the degradation that does occur is in the immediate vicinity of the few scientific stations. Even if the addition of a few year-around mineral exploitation activities in Antarctica raised the present levels of pollution (from scientific research and support activities) by an order of magnitude, this addition to the general decrease in land, air and water quality would still leave the environment relatively untouched compared to other areas of the world. However, the view has also been expressed that pollutants in the atmosphere over Antarctica would have an effect on the world climate by disrupting the radiation balance in the polar regions.

Some of the most spectacular scenery in the world is found in Antarctica. One aspect of its grandure is that it is still unspoiled by and devoid of human activity. Any resource exploitation, simply by its presence, would probably degrade the aesthetic value for those who were there to behold it. Presumably, however, there would be little conflict with other land use and human activities. If land use conflicts were to arise, it may be presumed that scientific investigation would continue to have priority.

ANTARCTIC ENERGY RESOURCES

COAL

Coal deposits, particularly in Victoria Land in East Antarctica, have been known since the early polar expeditions. Most coal seams are found in Permian and Jurassic rocks (see Geologic Time Scale, Figure 2) where they are exposed along the coast or in the Horlick, Pensacola, Theron, and Prince Charles Mountains. Most of the coal deposits appear to have formed in ancient shallow swamps on sandy flood plains. These coal beds are now dispersed throughout a Permian sandstone sequence that is usually more than 500 meters (1,600 ft.) thick.

Although individual beds as much as five meters (16 feet) thick have been reported, the coal beds usually range in thickness from a trace to a maximum of three or four meters (10 or 13 ft.). Most of the individual coal beds tend to be lenticular and extend horizontally less than one kilometer (0.6 mile). Available information, although by no means conclusive, suggests that the coal bearing formations extend from coast to coast under most of the great central ice mass.[1] The coal beds apparently range in rank from low-volatile bituminous to semianthracite. In general, the coal resources of Antarctica are considered submarginal.[2]

Several factors considerably reduce any future prospects of exploiting Antarctic coal resources. Much of the semianthracite is mixed with sand, slate, conglomerates, and other impurities to the point where it would require extensive crushing and large quantities of water for washing, screening, and flotation processes to separate the fuel from the rock.[3] Water is scarce in Antarctica which would severely limit coal preparation. The ash content of Antarctic coal is high, commonly ranging from eight to 20 percent. Much of the bituminous coal is also high in sulfur.

Another major difficulty in exploiting the coal resources in Antarctica is that the great majority of the deposits are in remote and inaccessible places, generally high on mountains and at some distance from a suitable shipping point on the coast. Thus, the known Antarctic coals will probably not be exploited for export in the near future.

Development of Antarctic coal deposits could become feasible if long-term activities were established at some inland point near a coal deposit. Local use of coal would have to be economically competitive with other power sources such as nuclear, solar, or fuel oil. The establishment of a long-term activity of a sizeable nature utilizing coal would probably depend on the discovery of some other mineral resource of very high value adjacent to a minable coal deposit. Thus far, although several locations are promising, no mineral deposits of high value and concentration have been reported in Antarctica. A number of coal deposits have been examined as possible fuel sources for scientific stations but none have been developed for this purpose.

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[1] Wright, N. A. and P. L. Williams. Mineral Resources of Antarctica. U.S. Geological Survey Circular 705. Washington, D.C., 1974, p. 15.

[2] *Ibid.*, p. 2.

[3] Potter, N. Natural Resource Potentials of the Antarctic. American Geographical Society, 1969, p. 27.

Oil and Natural Gas

POTENTIAL RESOURCES

There is not sufficient information available on which to base an estimate of the petroleum potential of Antarctica. However, the results of exploration for oil and gas on continents other than Antarctica, especially in the Southern Hemisphere, can offer some insight for speculation about possible Antarctic hydrocarbons. The onshore portion of the Antarctic continent does not, at this time, offer the possibility of petroleum production. The land is covered by a very thick cap of glacial ice which is in almost constant motion; and the sedimentary rocks which are exposed are, for the most part, metamorphosed and thus not conducive to occurrence of oil or gas.[4]

Parts of the Antarctic continental shelf, however, are ice free during certain seasons of the year and, if extrapolations of geology from surrounding continents are valid, the continental shelf of Antarctica may be expected to contain thick unmetamorphosed sediments. Evidence for the correctness of this assumption has been provided by marine geological and geophysical surveys, particularly in the Ross Sea region. Research vessels have carried out systematic shelf programs of bathymetry, sediment thickness determinations, magnetic and gravity surveys, and bottom sampling by piston cores and dredge hauls. In addition, deep rotary drilling and coring has been accomplished on the Antarctic continental shelf by the drilling vessel *Glomar Challenger*. Natural gas was detected in some of the cores. The evidence strongly suggests that the geologic history of Antarctica is closely linked to that of the other continents of the Southern Hemisphere and that each has developed continental shelves on which thick Cretaceous and Tertiary sediments have been deposited.[5] (See Figure 2 for geologic time scale.)

On some of the southern continents, sediments of these ages also accumulated in basins in areas that later became land. There is geophysical evidence of the existence of such onshore basins in the Antarctic as well, beneath the ice cap.

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[4] Wright, N. A., and Williams, P. L., op. cit. p. 15.

[5] Ibid., p. 16.

FIGURE 2.—GEOLOGIC TIME SCALE

Era, period, and epoch	Duration in millions of years (approximate)	Millions of years ago (approximate)
Cenozoic:		
Quaternary:		
Recent	(1)	(1)
Pleistocene	2.5	2.5
Teritiary:		
Pliocene	4.5	7.0
Miocene	19.0	26.0
Oligocene	12.0	38.0
Eocene	16.0	54.0
Paleocene	11.0	65.0
Mesozoic:		
Cretaceous	71.0	136.0
Jurassic	54.0	190.0
Triassic	35.0	225.0
Paleozoic:		
Permian	55.0	280.0
Pennsylvanian	45.0	325.0
Mississippian	20.0	345.0
Devonian	50.0	395.0
Silurian	35.0	430.0
Ordovician	70.0	500.0
Cambrian	70.0	570.0
Precambrian	4,030.0	4,600.0

[1] Approximately last 5,000 years.

Note: Formation of the Earth's crust about 4,600,000,000 years ago. The rocks of the earth's crust are divided into 4 major eras of time as shown on the above scale. The 3 younger eras are further subdivided into periods and epochs. The Precambrian, the longest and oldest era, witnessed the beginning of life and the evolution of simple plants and animals. The Paleozoic era was dominated by the invertebrate animals and fishes, the Mesozoic by reptiles (dinosaurs,) and the Cenozoic by mammals with man first appearing in the Pleistocene epoch. Commercial oil and gas deposits can occur in rocks of Paleozoic, Mesozoic, or Cenozoic age. The best prospects vary in age from region to region depending upon the local stratigraphic and structural conditions. However, ⅔ of the known oil and natural gas reserves lie in Mesozoic sediments, especially in Jurassic and Cretaceous rocks. About 30 percent of the oil and 10 percent of the gas deposits occur in the younger Cenozoic rocks, with the remaining world's hydrocarbon reserves being found in the older Paleozoic strata.

Source: Adapted from McAlester, A. Lee. "The History of Life." Prentice-Hall, Inc., 1968, p. 152.

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Oil and gas fields have been discovered onshore and offshore in South America; offshore in Australia; and onshore and offshore in Africa in sedimentary strata of Cretaceous and Tertiary age which range from about three to five kilometers (about 10,000 to 15,000 feet) in thickness.[6] The results of drilling in these areas to date indicates that most of these shelves will probably not be prolific producers, except in limited areas such as the southeast corner of Australia.

Present knowledge indicates the existance of accumulations of Tertiary and Quaternary sediments on the shelves of the Bellingshausen Sea, the Weddell Sea, and the Ross Sea. The Bellingshausen Shelf is believed to be geologically similar to the Pacific shelf of Chile, which has to date yielded only natural gas.[7] The Ross shelf, however, may resemble the shelf off southeast Australia, which has been found to contain significant amounts of oil and gas.[8] The Weddell shelf has been compared both to shelves off southern South America and South Africa; [9] and to Lake Maracaibo and the Gulf of Venezuela.[10]

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[6] Ibid.
[7] Ibid.

Comparisons of the Weddell Sea to continental shelves off southern South America and South Africa, where only small oil and gas fields have been discovered to date, results in quite different expectations for petroleum discoveries than comparisons with the Lake Maracaibo area with its major oil deposits. The Cretaceous and Tertiary stratigraphy of the Maracaibo basin has received much attention because of the area's very high productivity of petroleum. It has been established that the petroleum of the region was generated from rocks of Cretaceous and Tertiary ages that were deposited before the basin underwent final compression and uplift to its present state. Stratigraphic and structural relations in the Weddell Sea area are much less well known than those in Venezuela, where numerous holes have been drilled. Reported occurrences of Cretaceous and Tertiary sediments around the Weddell Sea suggest that depositional environments were similar to those prevailing in Cretaceous and Tertiary times in the Maracaibo basin.[11] The evidence available thus far appears consistent with the idea that sedimentary and testonic conditions in Late Cretaceous and Early Tertiary times around the Weddell Sea were not unlike those in the Maracaibo basin and that the accumulation of organic matter, subsequent maturation and mobilization of oil, and abundant opportunity for its accumulation are possibilities. The Weddell Sea would thus appear to show the greatest promise for petroleum deposits in the Antarctic.[12] Normally, the stable side of an oil producing basin is the more productive one, as is the case with Lake Maracaibo. By analogy, the southern part of the Weddell Sea near Berkner Island would be the most promising for petroleum exploration.[13]

Utilizing analogies such as those previously discussed, the U.S. Geological Survey has estimated a resource potential of 45 billion barrels of oil from the continental shelf off Marie Byrd Land. The estimate apparently does not include the oil potential from the Weddell Sea, particularly as compared to Lake Maracaibo. The 45 billion barrel figure estimated is the total in-place oil that might be discovered in offshore Marie Byrd Land Antarctica. On the average, only about one-third of the in-place oil can be recovered, thus an in-place oil resource number is approximately three times larger than what one could expect to recover. The Antarctic recoverable resource estimate of the Geological Survey is therefore 15 billion barrels of oil.[14] Similar estimates place potential gas reserves at about 115 trillion cubic feet. Recovery from the Weddell Sea, using the Lake Maracaibo analogy, could be projected to exceed the 15 billion barrels of oil estimated from offshore Marie Byrd Land.

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[8] Ibid.

[9] Ibid.

[10] Deuser, W. G. Lake Maracaibo and Weddell Sea: Comparison in Petroleum Geology. The American Association of Petroleum Geologists Bulletin, v. 55, n. 5, May 1971, p. 705–708.

[11] Ibid. p. 707.

[12] Ibid. p. 708.

[13] Ibid.

[14] Masters, Charles D. Estimating the Antarctic Oil Resources. Washington Post, March 12, 1975.

The Soviet Union plans to establish a new 50 man station on the coast of the Weddell Sea, mainly to prospect for mineral resources. According to a Tass announcement [15] the new base will be built at the northern edge of the Filchner Ice Shelf, which extends into the Weddell Sea. The work of the Soviet team of geologists, geophysicists, and cartographers will extend over a five year period and will cover the region extending from the Antarctic Peninsula to Queen Maud Land, the entire coast line of the Weddell Sea. The Soviet announcement stated that the most extensive continental shelf in Antarctica and a potential storehouse of oil and gas extends across the Weddell Sea and the Filchner Ice Shelf and indicated Moscow's interest in the mineral resources of the area.[16] In fact, the former director of the Soviet Union's Institute for Arctic Geology predicted at the end of 1974 that oil exploration on the Antarctic coastal shelf is an entirely realistic prospect in the very near future and that it would be followed by production.[17]

TECHNOLOGY

Regardless of their potential, the continental margins of the Antarctic continent differ from the margins of other continents in that they are covered by a much greater depth of water. The seaward edge of the Antarctic continental shelf averages at least 500 meters (1,650 feet) below sea level, which contrasts to an average depth of about 200 meters (600 feet) for most of the shelves of other continents. The base of the continental slope of Antarctica appears to be at about 3,000 meters (9,800 feet) below the level of the sea as compared to about 2,500 meters (8,200 feet) for most of the rest of the world. The continental slope is also apparently steeper than those in most other areas. Such drilling is not yet routine in the offshore petroleum industry, but at least 60 petroleum tests have been drilled in water deeper than 200 meters (600 feet) around the world since 1965.[18] Almost any depth of water to 300 meters (1,000 feet) is considered inside industry's ordinary capability.[19] Exploration drilling below 300 meters is fairly common and a well at 1,000 meters (3,300 feet), while not as yet drilled, is now believed to be within the bounds of industry technology.[20] To date, there have been about a dozen exploration wells drilled in water depths exceeding 300 meters (1,000 feet). On the West Coast of Africa, off Gabon, test wells have been drilled in 645 meters (2,150 feet) and in 690 meters (2,300 feet) of water.[21]

In addition to the greater depths and, of course, the tremendous logistical problems in Antarctic operations, are the problems caused by ice. Many new ideas have been suggested as possible methods of dealing with ice, however, with some exceptions the solution thus far appears to have been to avoid working in areas when ice is present. The forces created by ice as it forms or moves can buckle the sides of a drill ship not specially designed or reinforced and can also force it off the drillsite. An iceberg, if large enough and moving fast enough, can destroy a drillship or be so large (many Antarctic icebergs are tens of kilometers long) as to scrape the bottom destroying blowout preventers or any other exploration or production equipment which projects above the seafloor. Given enough warning a drillship could shut in a hole and move away from a dangerous area then occupy the site later. This could be costly, however, depending upon the frequency of such an activity. More will have to be discovered about regular patterns of iceberg movements, if they exist.

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[15] Browne, Malcolm W. Soviet Plans New Station on Shores of Antarctica. New York Times June 29, 1975.

[16] Ibid.

[17] Ocean Oil Weekly Report, v. 9, n. 10, December 2, 1974, p. 2.

[18] Drilling Technology Keeps Pace with Deep Water. Offshore, June 5, 1975, p. 46.

[19] Ibid.

[20] Ibid.

[21] Worldwide Drilling and Production: Offshore Drilling Records, Offshore, June 20, 1975, p. 71.

The petroleum industry is currently conducting research on drilling and production systems for ice-prone offshore Arctic areas, many of which probably could be adapted with modifications to Antarctica. Such equipment as icebreaking drillships; monopod rigs with ice-cutting columns; and air cushion snow drillers have been proposed, designed, and, in some cases, modeled and tested.

GEOTHERMAL ENERGY

Geothermal energy is a product of the natural heat of the Earth. The temperature of the earth increases inward toward the core due to natural nuclear decay and the frictional heat of large moving rock masses. Most of the Earth's heat, however, is far too deeply buried and diffused to be utilized. Geothermal energy does have potential economic significance, however, where the heat is concentrated into restricted volumes in a manner somewhat analogous to the concentration of metals into ore deposits or oil into petroleum reservoirs. Economic geothermal deposits consist of elevated temperatures at shallow depths, the heat energy being stored both in hot solid rock and in hot water and steam filling rock pores and fractures. The heat in many geothermal reservoirs is derived from large bodies of hot molten rock (magma) that have moved upward into the Earth's crust from great depths. These hot bodies of magma heat the adjacent rocks in the crust near the surface, which in turn heat the water contained in any fissures or pores. The heated water then serves as the medium by which heat is transferred from the magma to the geothermal reservoir at depths shallow enough to be reached by drilling.[22] The steam and heated water can be used locally for space heating and for conversion to electric power.

Most potential geothermal resource areas in Antarctica are related to active or recently active centers of volcanic eruption. These centers are located along much of the Pacific margin of the continent; including the western border of the Ross Sea, Marie Byrd Land, and the South Shetland Islands off the northwest coast of the Antarctic Peninsula.[23]

Indications of geothermal potential, other than recency of eruption, are silica-rich magmas and large volcanic rock volumes. Silica-rich magmas which erupt to form high silica rocks such as rhyolites and dacites are derived from shallow magma chambers with a heat source relatively accessible to ground water, thus providing conditions favorable for the development of geothermal deposits. Large volumes of volcanic rock, such as are found along the Pacific margin of Antarctica, indicate the presence of large magma chambers beneath the surface. The large chambers constitute a greater heat source for potential geothermal deposits than would smaller magma accumulations.[24]

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[22] Riva, Joseph P., Mielke, James E., Dyas, Norma W., and Justus, John R. Energy from Geothermal Resources. Report Prepared for the Subcommittee on Energy, House Committee on Science and Astronautics, U.S. Government Printing Office, Washington, D.C., May 1974, p. 12.

[23] Wright, N. A., and Williams, P. L., op. cit., p. 12.

Silica-poor magmas, such as basalt, are normally derived from heat sources deep within the crust which are usually inaccessible to ground water or to direct drilling. The great preponderance of such silica-poor volcanic rocks, indicating deep and inaccessible heat sources, suggests a rather low overall potential for geothermal heat development on the Antarctic continent. The best prospects are in areas where fumarolic activity has been observed. Fumaroles are volcanic vents from which gases are emitted and indicate a heat source at or near the surface. Second-rank prospects are in areas where eruptions have occurred in the recent geologic past and where there are indications of the possibility of future eruptions.[25]

In the Ross sea region, large amounts of young volcanic flows occur along the coast of southern and northern Victoria Land and make up several offshore islands. Fumarole activity has been reported at the summit of Mount Erebus since the 1840's and the floor of the summit crater contains a pool of molten lava.

In none of the areas judged favorable, can the geothermal potential be considered great. Conceivable, a small geothermal plant, if technically and economically feasible, might serve McMurdo Station (U.S.) and Scott Base (New Zealand) which are both on Ross Island.[26] Fumarole activity has also been reported at Mount Morning, located about 140 kilometers southwest of Mount Erebus.

Fumaroles have been observed at Mount Melbourne in the Hallet volcanic province of northern Victoria Land, an area of very recent volcanic cinder cones. In Marie Byrd Land there are several young basalt cones and fumaroles are present on the summits of Mount Berlin and Mount Hampton.

Geologically the most favorable prospect for the development of geothermal energy in Antarctica would appear to be Deception Island in the South Shetland Island group.[27] Deception Island is a geologically recent caldera where fumarole activity has been observed since 1831. Two violent eruptions occurred in 1967 and 1969. Account, however, must be taken of the importance of water in connection with the volcanic phenomena at Deception Island and in other volcanic areas believed to have geothermal energy potential. Generally, the presence of water is an important element for the exploitation of geothermal energy because it is a good medium for transmitting heat. In the case of Deception Island, however, the abundance of water may prevent direct exploitation as it absorbs the greatest part of the heat energy produced.[28]

Some bore holes might be drilled in order to search for steam, but the cost of such exploration would probably not be justified to obtain the limited amount of energy needed to supply the small scientific bases for which the island has been used. However, given the rising costs of fossil fuels and the advances in geothermal technology, it may, at some future date, be feasible to utilize geothermal energy to provide heat and electric power to some of the Antarctic stations located in the geologically favorable areas previously listed, particularly where local geothermal conditions are optimal.

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[24] Ibid., p. 14.
[25] Ibid.
[26] Ibid.
[27] Ibid.
[28] Castertano, Lorenzo. Volcanic Activity at Deception Island. Antarctic Geology. Proceedings of the First International Symposium of Antarctic Geology. North-Holland Publishing Company, Amsterdam, 1964, p. 46.

OTHER ENERGY RESOURCES

URANIUM

There are few reports of uranium occurrences in Antarctica. The uranium mineral, euxenite, is dispersed as an accessory mineral in Precambrian rocks in the Lutzow-Holm Bay area of East Antarctica, near the Japanese station of Syowa.[29] Uranium minerals have also been reported in the Antarctic Peninsula.[30] French geologists have reported anomalous amounts of radioactivity in the Adelie Coast. No significant uranium occurrences have been reported.

SOLAR

Solar energy is generally regarded as having greater potential for development in latitudes nearer the equator than in polar regions. Latitude strongly affects the amount of solar radiation a horizontal surface receives. At high latitudes the sun does not get directly overhead. When the sunshine strikes at an angle, the radiation is spread over a larger area, therefore, there is less energy per unit area than if the sunshine struck perpendicular to the horizontal. For the same reason, the time of day also affects the amount of solar energy collected by a fixed surface. Latitude influences the duration of sunshine in any day and the distribution of sunshine with the seasons. In the summer season, the longer duration of sunlight at higher latitudes helps compensate for higher intensities at lower latitudes.

Other factors influence the amount of solar energy received by a surface, such as atmospheric pollution, elevation, degree of cloudiness and ground reflection. Most of these factors combine to maximize the amount of solar radiation that can be collected in high polar regions such as the interior of Antarctica. Fresh snow reflects about nine times as much radiation as bare ground. The higher the elevation the less the atmospheric filtering, and there is relatively little atmospheric pollution over Antarctica. Consequently, through the use of solar collectors inclined to achieve an optimum angle with the sun and exploit the reflected radiation, solar radiation could be considered an important supplementary energy resource for local use during the summer season.

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[29] Antarctic Resources—Report from the meeting of experts at the Fridtjof Nansen Foundation at Polhogda. May 30–June 10, 1973. In U.S. Antarctic Policy, op. cit., p. 71.

[30] U.S.G.S. Circular 705, op. cit., p. 11.

INTERNATIONAL RELATIONS

Early Discoveries and Claims

There is some uncertainty as to who first discovered Antarctica. Initial mention of the continent goes back to the ancient Greeks who postulated that a great southern continent existed to "balance" the continents in the north. The Maoris of New Zealand also have vague legends of a white land somewhere to the south.

Documented Antarctic history begins with the voyages of Captain James Cook of the British Navy. Captain Cook sailed completely around the continent between the years 1772 and 1775. His two ships probed south at several points, but each time they were turned back by heavy pack ice without sighting land. He did observe birds which he believed came from land further south. One significant accomplishment of Captain Cook's in the Antarctic was his discovery of South Georgia Island in the South Atlantic. Here he reported seeing fur seals which soon served as a magnet drawing American and British seal hunters further south.

It seems likely that seal hunters were the first to actually sight Antarctica. However, since they frequently kept their discoveries secret to protect their hunting areas, there are no existing records of the discovery of Antarctica before 1820. On January 30th of that year, a British ship under Captain Bransfield reported sighting what may have been the mainland or what may have been an island off the coast of the Antarctic Peninsula. During the same year two Russian ships under the command of Admiral Bellingshausen sighted at several places what might have been land or might have been icebergs frozen in the pack. Bellingshausen would make no claim until he was sure. Finally, on January 28, 1821, he saw a mountainous coast which he named Alexander I Land. Alexander I Land has since been shown to be a large island separated from the continent.

Meanwhile, on November 18, 1820, an American, Captain Nathaniel B. Palmer, sighted the continent near the tip of the Antarctic Peninsula. On February 7, 1821, another American, Captain John Davis, sent a boatload of men to look for seals on the shore of what is now called Hughes Bay on the continent itself. The existence of a continental size land mass was firmly established by 1840 as three separate expeditions (French, British, and American) sighted land at many points around the coast of Antarctica.

There was little activity in the Antarctic for the next 50 years, but by the end of the century, spurred by new methods of whaling and scientific curiosity, interest renewed. The first expedition to winter over in the Antarctic was Belgian who spent the winter of 1898 aboard their ship frozen in the ice pack. The next year a British expedition spent the winter on land, and in 1901 a weather station was set up on Laurie Island in the South Orkney Islands. This station has been operated by Argentina since 1904. Expeditions have been carried out nearly every year since 1901. The South Pole was finally reached in 1911–1912 by Roald Amundsen of Norway and a month later by Robert Scott of England. An American, Admiral Richard E. Byrd, is the person mostly credited with introducing mechanized exploration and airplanes to Antarctica in the late 1920's and 1930's. Following World War II several countries extablished bases in Antarctica, mostly in the area around the Antarctic Peninsula.

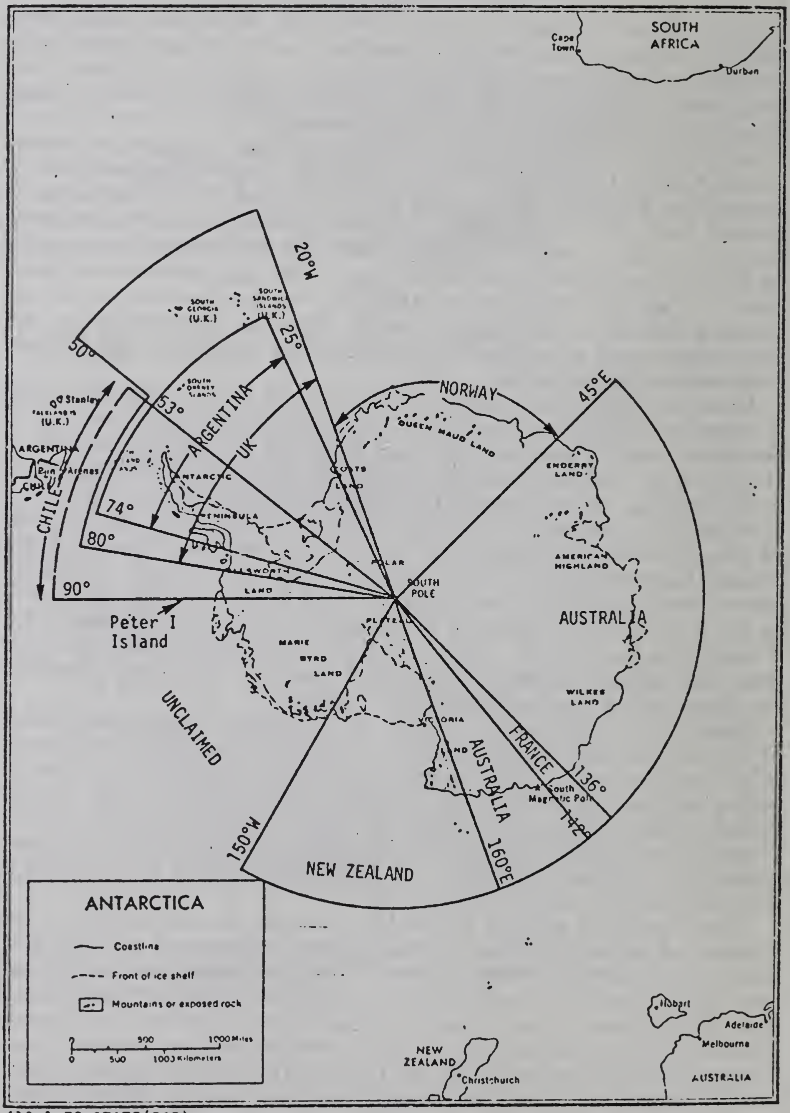

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FIGURE 3.—Claims of national jurisdiction in Antarctica.
Source: U.S. Department of State.

In the first half of the 20th century seven countries claimed sovereignty over territory in Antarctica (Fig. 3). These countries are Argentina, Australia, Chile, France, New Zealand, Norway, and the United Kingdom. All except Norway have claimed wedge-shaped sectors terminating at the South Pole. Norway has claimed the coastal area between 20° West Longitude and 45° East Longitude, but has left vague the southern terminus apparently to avoid damage, by implication, to its position of opposition to the Soviet sector approach in the Arctic. The claims of three of the countries, Argentina, Chile, and the United Kingdom, overlap and conflict in the area of the Antarctic Peninsula, which is south of Cape Horn.

Territorial claims in Antarctica have not received general recognition by the international community. Mutual recognition of claims has been limited to Australia, France, New Zealand, Norway, and the United Kingdom. While Chile and Argentina do not recognize each other's claim, in 1941 they issued a joint declaration that the only countries with exclusive sovereignty over Antarctica are Chile and Argentina.[1] The United States, the Soviet Union, and several other interested states have made no territorial claims in Antarctica and do not recognize the claims of others. However, they reserve all their basic historic rights in the continent. Although it has been suggested that the United States would be justified in claiming territory in Antarctica, such as the unclaimed sector between 90° and 150° West Longitude, out of hope for an international solution to territorial claims, the United States has not advanced any claims of its own.

The U.S. position on Antarctica derives from a policy statement in 1924 by Secretary of State Charles Evans Hughes who wrote, "It is the opinion of the Department that the discovery of lands unknown to civilization, even when coupled with a formal taking of possession, does not support a valid claim to sovereignty unless the discovery is followed by an actual settlement of the discovered country."[2]

However, in the instructions issued on November 25, 1939, to Rear Admiral Richard E. Byrd as Commanding Officer, U.S. Antarctic Service, President Franklin D. Roosevelt pointed out the importance of sovereignty claims of the U.S. position in the area:

> The United States has never recognized any claims of sovereignty over territory in the Antarctic regions asserted by any foreign state. No member of the United States Antarctic Service shall take any action or make any statements tending to compromise this position.
>
> Members of the Service may take any appropriate steps such as dropping written claims from airplanes, depositing such writing in cairns, et cetera, which might assist in supporting a sovereignty claim by the United States Government. Careful record shall be kept of the circumstances surrounding each such act. No public announcement of such act shall, however, be made without specific authority in each case from the Secretary of State.[3]

No territorial claims have been advanced as a result of these activities.

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[1] Kish, J. The Law of International Spaces, A. W. Sitjthoff, Leiden, 1973, p. 30.

[2] The United States in the Antarctic 1820–1962. U.S. Antarctic Project Office, Washington, D.C., 1962, p. 26.

[3] Ibid., p. 27.

Photo by James E. Mielke

Otter (De Havilland Canada) equipped with skis, on Axel Heiberg Island, N.W.T., Canada. Typical of the light bush planes that have been used to transport field parties into remote polar locations. Otters were first used in Antarctica by the U.S. Navy during "Operation Deep-Freeze" in 1956–58. Nine other nations have used Otters or the smaller Beaver in Antarctica.

In 1946, the United States mounted the largest Antarctic expedition ever, involving nearly 5,000 men in Operation High Jump. Together with Operation Windmill the following year, the United States demonstrated a significant interest in the continent. Following this burst of activity the United States proposed that in many fields significant results could best be obtained from observations conducted over a period of years or even decades. In 1949, the National Academy of Sciences recommended the creation of an international scientific program in Antarctica with free exchange of information among various parties involved.

The International Geophysical Year

In 1950, a group of American and British scientists suggested a 1957–1958 International Geophysical Year to coincide with a predicted period of unusual sunspot activity. The proposal was presented to the International Council of Scientific Unions (ICSU) which endorsed the proposal in 1951. The concept of a global International Geophysical Year (IGY) evolved in 1953. Because of the long lead times required to prepare for extensive programs in Antarctica, preparations began in 1954.

The high point of activity in Antarctica was reached during the period preceding and throughout the International Geophysical Year (IGY) which officially began on July 1, 1957. Twelve nations participated in Antarctic studies and established 60 stations there. The

United States effort during the peak 1956–1957 season involved 3,000 men, 12 ships, and numerous aircraft. U.S. scientists alone shipped back 27 tons of data during the IGY. By the time the IGY was drawing to a close, many scientists and diplomats felt that the program in Antarctica was too valuable to terminate and that the international cooperation achieved during IGY should be maintained.

THE ANTARCTIC TREATY

As early as 1948 the United States had proposed an international solution to territorial claims in Antarctica by which Antarctica would be governed by a trusteeship under the United Nations, but the proposal drew slight interest from only two of the claimants, the United Kingdom and New Zealand. In 1956 India presented a similar proposal before the United Nations and met with little success. Discussions of Antarctic claims among Australia, New Zealand, and the United Kingdom also produced no results. Throughout the IGY the status of Antarctica was not only politically unresolved, but the issue was successfully submerged to avoid political controversies that might be detrimental to scientific cooperation. Subsequent scientific activities in the Antarctic demonstrated that scientists of various countries, including those having overlapping Antarctic claims, could work peacefully together, relatively unaffected by unresolved political difficulties. This harmony was due in part to common scientific objectives and partly to the forbidding nature of the area. In a sense, the expeditions were bound together by a common enemy, the environment. An additional factor was that scientists were not personally responsible for protecting their respective national interests in the area, since such interests were not at stake in the IGY.

It soon became clear to the nations involved in Antarctic research that there would be a significant benefit if the work begun during IGY could be continued. On May 2, 1958, the United States proposed to the other participants, Argentina, Australia, Belgium, Chile, France, Japan, New Zealand, Norway, the Soviet Union, the Union of South Africa, and the United Kingdom, that they should join "in a treaty designed to preserve the continent as an international laboratory for scientific research and insure that it be used only for peaceful purposes."[4] Preliminary talks in Washington were stalled by Chilean and Argentine reluctance to agree to international control and by Soviet objections to the existing Antarctic claims of other nations. Eventually a treaty was agreed upon and signed on December 1, 1959.

Japan became the first nation to ratify the treaty on August 4, 1960. U. S. ratification followed on August 18, 1960, and the treaty entered into force for the United States on June 23, 1961 (Appendix I). The major provisions of the treaty are as follows:

Article I. Antarctica shall be used for peaceful purposes only. All measures of a military nature, including weapons testing, are prohibited.

Article II. Freedom of scientific investigation and cooperation shall continue.

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[4] U.S. Congress. House, Committee on Foreign Affairs. Subcommittee on National Security Policy and Scientific Developments. The Political Legacy of the International Geophysical Year. Committee Print by Harold Bullis, Congressional Research Service, U.S. Government Printing Office, Washington, 1973, p. 57.

Article III. Scientific plans, personnel, observations, and results shall be freely exchanged.

Article IV. Signatories do not recognize, dispute, or establish territorial claims.

Article V. Nuclear explosions and the disposal of radioactive wastes in the area are prohibited.

Article VI. All land and ice masses below 60 degrees south latitude are included, but international law with regard to the high seas shall prevail.

Article VII. Observers from treaty nations have the right of free access to any area and may inspect all stations, installations, and equipment within those areas. Aerial observations are permitted, and each signatory must provide advance notice of its activities within the area.

Article VIII. Observers under Article VII and scientific personnel exchanged under Article III are under the jurisdiction of their own state and not their host.

Article IX. Parties to the Treaty will meet to exchange information and to recommend measures to further all of the above provisions of the Treaty including the preservation and conservation of living resources.

Article X. Parties to the Treaty are expected to encourage other nations to abide by the Treaty.

Article XI. Provision is made for peaceful settlement of disputes over interpretation and application of the Treaty.

Article XII. Provision is made for modification and amendment of and withdrawal from the Treaty.

Article XIII. Provision is made for ratification.

The Antarctic Treaty does not contain any provisions which specifically mention non-living resources. (Living resources are mentioned in Article IX.) Recognizing the possibility of future pressures to commercially develop Antarctic mineral resources, the United Kingdom delegation to the sixth Antarctic Treaty Consultative Meeting (1970) moved to place the subject, "Antarctic Resources—Effects of Mineral Exploration", on the agenda of the Seventh Consultative Meeting in Wellington, 1972. Finding that the issue was highly charged, the delegates meeting in Wellington decided to postpone further discussion until the Eighth Consultative Meeting in Oslo (1975) in order for their governments to have further time to study the matter. After much discussion, the nations meeting in Oslo approved a statement recommending that they exercise restraint from commercial exploration and exploitation as long as an international solution to the problem is being sought. Robert Hughes, assistant director of the National Science Foundation and head of the U.S. delegation to Oslo was quoted, "I think all governments showed a very deep resolve to preserve the treaty." [5]

The compatability of commercial mineral recovery in Antarctica under the present Treaty is subject to interpretation. Several views have been expressed. According to one view, it would not be possible to begin commercial mineral exploration in the Antarctic without amendment of the Treaty, as serious problems would arise. Supporters of this view have generally held that commercial mineral exploration would constitute a serious threat to the Antarctic ecosystem, disturb scientific activity, contaminate the seas, ice and land, and raise problems of territorial jurisdiction in violation of Article IV of the Treaty.

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[5] Science, v. 189, August 1, 1975, p. 365.

According to another view, the Antarctic Treaty does not prohibit exploration and exploitation of mineral resources. Any nation party to the Treaty could now engage in such activity without violating the Treaty, provided the activity was consistent with relevant provisions of the Treaty and Recommendations adopted at Consultative Meetings. The relevant provisions are: that such activity is for peaceful purposes (Preamble and Article I), not conflict with freedom of scientific investigation (Article II), include exchange of information and research (Article III), rights of inspection (Article VII), comply with obligations to provide notice of expeditions (Article VII), and not violate Specially Protected Areas, protect the environment, and not cause harmful interference with fauna and flora (Recommendations III–IX). Supporters of this view hold that although commercial mineral exploitation is not one of the matters specifically included in Article IX, it is a matter about which the consultative parties can meet to resolve multinationally.

A third view suggests that since the Antarctic Treaty does not directly prohibit and at the same time does not permit commercial exploration and exploitation of mineral resources, it does not directly govern this matter. However, any such action (unilateral, bilateral or multilateral) by contracting parties will be contrary to the purposes and objectives of the Treaty and should be considered a violation of the Treaty if the action were undertaken before the consent of all consultative parties has been given. Supporters of this view consider that commercial mineral recovery without the consent of all parties would be incompatible with the following provisions of the Treaty:

1. "Antarctic . . . shall not become the scene or object of international discord" (Preamble).
2. "a treaty ensuring . . . the continuance of international harmony in Antarctica will further the purposes and principles embodied in the charter of the United Nations" (Preamble).
3. "Each of the Contracting Parties undertakes to exert appropriate efforts, consistent with the charter of the United Nations, to the end that no one engages in any activity in Antarctica contrary to the principles or purposes of the present Treaty". (Article X).

While the issue of commercial mineral exploitation raised by the United Kingdom may seem somewhat premature, technology is advancing and the demand for mineral resources, especially energy resources, is increasing. Furthermore, the Antarctic Treaty provides for modification and amendment (Article XII) to accommodate newly developed concerns. Peaceful resolution of the mineral resource problem would greatly aid in avoiding territorial conflicts that might arise if contracting parties should withdraw from the Treaty now that Antarctica has been continuously occupied by several countries for twenty years. It has been pointed out that the basic problem in mineral development is security of title, and that issue could only be resolved by dealing with the problem of territorial sovereignty. The present Treaty can shelve this problem because scientific research does not require its resolution.

The question of sovereignty in Antarctica is further complicated by whether a land or high seas regime should be applied to Antarctica since parts of the continent lie below sea level and would be considered part of the high seas in the absence of the ice sheet. However, since the ice sheet is unlikely to melt in the reasonably near future, some argue that political considerations based on that possibility tend to confuse rather than clarify the issue of sovereignity. According to article VI of the Antarctic Treaty, "The provisions of the present Treaty shall apply to the area south of 60° South Latitude, including all ice shelves, but nothing in the present Treaty shall prejudice or in any way affect the rights, of any State under international law with regard to the high seas within that area." According to this article, areas of the continental shelf and the deep seabed would then be within the high seas regime.

Normally a coastal state extends its territorial limits to include a portion of the continental shelf offshore. However, in the case of Antarctica where there is a lack of general recognition of territorial claims this also affects claims extended onto the continental shelf. This is an important consideration since the energy resource with the greatest potential and the most likely to be exploited (although not in the immediate future) would be fluid hydrocarbons from the continental shelf. These lie, then, in areas subject to the international law of the high seas.

After several years of preparation, the Third U.N. Law of the Sea Conference convened in 1973 followed by sessions each succeeding year. The purpose of this conference is to establish by general international agreement a treaty that would detail, among other things, the territorial limits of coastal states, possible economic zones on the continental shelf, and a regime for exploiting the resources of the deep seabed. Agreement on such a treaty is still lacking and may be several years in attaining, if it can be attained at all.

The U.N. General Assembly adopted in 1970 by a vote of 108 to 0 with 14 abstentions, a "Declaration of Legal Principles" which stated:

> The seabed and ocean floor, and the subsoil thereof, beyond the limits of national jurisdiction, as well as the resources of the area, are the common heritage of mankind.[6]

The United States voted for this resolution. The Antarctic Treaty partners may find it advantageous to settle the issue of resource exploitation in Antarctica within the confines of the present treaty or by a separate treaty among themselves but open to whomever else may wish to join. The prospects of a future Law of the Sea Treaty governing resource exploitation of the Antarctic continental shelf would likely dilute the influence the present Antarctic Treaty partners have in the area. This may provide sufficient incentive for the treaty partners to reach an accord on resource exploitation throughout Antarctica, or possibly agree to a moratorium on any exploitation until such an accord can be reached.

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[6] United Nations Doc A/6228, 1970.

SUMMARY

At the present time there are no known commercially economic energy resources in Antarctica. Probably the most promising potential energy resources for future development would be petroleum or natural gas. Neither have been found in significant quantity in Antarctica, but there are indications, supported by geologists' hypotheses, that a moderately large resource exists. The most favorable prospects for oil and gas accumulation in Antarctica are in the Cretaceous and Tertiary sediments on the continental shelf. Estimates of the recoverable hydrocarbon resources in Antarctica range upward from 15 billion barrels of oil and 115 trillion cubic feet of gas.

Recovery of oil and gas from offshore areas in the Antarctic would present immense technological and logistical problems. However, the petroleum industry is currently conducting research on drilling and production systems for ice-prone offshore areas of the Arctic; technology which if successfully developed, could possibly be transferred with modifications to the Antarctic.

There is too little information to estimate Antarctic coal resources at the present time. There are indications that coal bearing formations could extend from coast to coast under the massive ice sheet, but it is not likely that such a hypothetical resource, even if immense, could be economically exploited in the near foreseeable future. Unless high grade uranium ore is discovered in quantity in the near future in Antarctica, it is not likely that other Antarctic energy resources would be exploited other than for local use.

In absence of specific language in the Antarctic Treaty regarding mineral exploitation, there is a great amount of uncertainty as to what would develop if a commercially economic resource were discovered. The situation would be further complicated by the conflict over territorial claims, temporarily held in abeyance but unresolved by the Antarctic Treaty. In an attempt to forestall the problem of mineral development before it might arise, the consultative parties to the Antarctic Treaty have begun preliminary discussions of the problem. Furthermore, in any hypothetical resource development in Antarctica, environmental concerns would be a major issue.

PART II. ARCTIC (North of 60°)

INTRODUCTION

A theme of immenseness describes the Arctic. The aspect that is very striking, and generally leaves a lasting impression on one who has traveled through the Arctic, is the immense uninhabited areas. Not only are the polar regions immense but they are immense distances from major population centers where energy resources are needed and consumed. Consequently, for potential energy resources of the Arctic to be economically attractive, other than for local use, the resources themselves must be immense and they will likely require immense amounts of capital to develop. Furthermore, engineering and construction problems may, in some cases, also be immense. Development while preserving the unspoiled beauty and often fragile ecology of some Arctic areas is also of immense concern. However, what is now considered impossibly immense may become commonplace in the future. For example, not long ago a 70,000 dwt tanker was a large ship and a 500,000 dwt tanker would have been inconceivably large. Finally, in a world of diminishing fossil energy resources, especially those that are located in temperate zones, the ultimate rewards of developing additional energy resources are also likely to become immense.

Although vast energy resources are known in the Arctic regions, until recently these energy resources have been largely unexploited except for local use. The Arctic population is small and, therefore, the tendency is to consider the significance of Arctic resources mainly in terms of their value to people who live outside the Arctic. In this regard, the major consideration becomes whether or not it is economically feasible to transport an Arctic energy resource to southern markets. A possible future trend may be the development of Arctic areas into energy consuming areas through the processing of ores and raw materials into finished products. For example, in Arctic Russia metals in the Noril'sk mining area are processed and refined using local energy resources, and in Iceland ore is imported, refined using abundant hydroelectric power, and the metal is exported. Studies have also projected that natural gas from Alaska's North Slope may form the basis of a petrochemical industry in Alaska.

Faced with the prospect of increasing shortages of petroleum and natural gas, a considerable effort is now going into development of these Arctic energy resources. In the forefront of this development is the United States' effort to bring petroleum down from the Arctic coast of Alaska through the trans-Alaska pipeline now under construction. Future construction of a gas transmission line from the same area is expected. A large research effort has gone into the development of technology and construction techniques for recovering the Alaskan oil and gas resources in an environmentally responsible manner. Additional research into the nature of the Arctic environment is likely to continue at a relatively high level for several years, both to monitor areas under development and to prepare for possible resource development in new areas.

Large coal deposits are also found along the north coast of Alaska. Current transportation economics prevent the large-scale exploitation of this resource although an export market could possibly be developed from coastal mining areas if a demand should arise. Transmission of synthetic natural gas (SNG) from coal could also possibly be developed in the future, if an existing gas pipeline were available and other economic considerations became favorable.

In other Arctic areas, Canada, Norway, and the Soviet Union are also actively engaged in exploration for oil and gas. The Canadians and Norwegians have designs for and have developed new technology and techniques for Arctic oil and gas exploration and development, but the Soviets appear to be relying primarily on purchasing new technology from the West and utilizing older existing designs. Added together the energy resource potental of the Arctic regions is immense and the technology to develop the energy resources is forthcoming.

For the purposes of this report the Arctic regions covered will, in general, consist of those areas above 60 degrees north latitude. In some instances resources slightly below 60 degrees will also be treated for completeness.

ENVIRONMENT AND TERRAIN

CLIMATE AND WEATHER

One aspect of the northern climate that has a significant effect on surface conditions is whether or not there is snow or ice cover. A fresh snow covered surface will absorb up to 20 percent of the available solar radiation whereas more than 80 percent will be absorbed in snow-free regions. The immediate effect of changes in this cover on the heat exchange at the surface is so great that the Arctic region can be said to have only two seasons, with a rapid transition of about a week during the spring thaw and during the fall freeze. Over the permanent ice caps the air temperature remains at about 0° C. during the relatively short summer, but in snow or ice free areas the air temperature can reach 21 to 29° C. (70 to 85° F.). The contrast between presence and absence of snow or ice cover plays an important role in the modification of air masses crossing the region. Cyclones and anticyclones depend on temperature contrasts and frequently develop at the margins of snow or ice cover.

Occasional open leads in the winter provide moisture to the air, but the coldness of the air reduces the amount of moisture that can be held. Consequently, the greater part of the Arctic is virtually a desert and the precipitation that does fall is usually in the form of small, dry, hard snow particles which are easily redistributed by the wind to produce blowing-snow storms. In the summer, open water in the ice pack and near the coast produces low clouds and fog in coastal areas. The combination of overcast sky and an unbroken snow or ice surface produces the optical phenomenon of a whiteout, which is a shadowless condition in which visibility is seriously impaired through loss of depth perception.

Photo by James E. Mielke

Mining an iceberg for fresh water in Tanquary Fiord, Ellesmere Island, N.W.T., Canada. Despite the abundance of ice, the polar regions are for the most part arid, and securing a supply of fresh water can be an effort.

Colder temperatures can be reached on the continental areas than at the north pole, although with the longer winter at the pole low temperatures are more persistent. The coldest temperatures have been recorded where cold dense air is trapped in hollows and valleys as in the Yukon and northeastern Siberia. Cold dense air appears to drain off the convex surfaces of the ice caps in surges by gravitational flow.

Based on annual temperature curves the Arctic can be divided into at least three climatic types: maritime, coastal, and continental.[1] The air temperature over the Arctic Ocean ranges from around the freezing point in June, July, and August to around −34° C. (−29° F.) during the winter season with relatively small fluctuations. The coastal climate is similar to the maritime except for a warmer summer season with a temperature maximum in July. However, the mean summer temperature in the coastal areas remains below 10° C. (50° F.) making the short summer season comparable to the spring and fall of the continental climate. The Arctic continental climate is characterized by very low winter temperatures with a pronounced winter minimum and high summer temperatures with a very pronounced summer maximum. The annual range of mean temperature on the continents may be as much as 72° C. (130° F.).

Ocean Areas

THE ARCTIC OCEAN

The Arctic Ocean surrounds the North Pole and is bordered by Greenland, Canada, Alaska, Siberia, and Scandinavia. It covers about

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[1] Sater, et. al., op. cit., p. 134.

10.4 million square kilometers (4 million square miles) in area and reaches depths of over 4,270 meters (14,000 feet). The Arctic Ocean connects and interacts with the Atlantic through two major seas, the Norwegian Sea and the Greenland Sea. The connection with the Pacific through the Bering Strait is of relatively minor importance oceanographically. Important processes affecting the Arctic Ocean water are heat transfer with the atmosphere, salinity changes through melting and freezing of ice, the addition of fresh water from land run off (primarily from the large Siberian rivers) and water exchange with the North Atlantic.

The continental margin on the Eurasian side contains some of the broadest continental shelves in the world. The Barents and Kara shelves are 560 to 970 kilometers (350 to 600 miles) wide, and the East Siberian Shelf is 400 to 725 kilometers (250 to 450 miles) wide. Much narrower shelves ranging from 25 to 55 kilometers (15 to 35 miles) are found north of Greenland and Canada except for the northwestern edge of the Canadian Archipelago where the shelf widens to nearly 160 kilometers. The shelf north of Alaska is about 80 kilometers wide and broadens greatly into the Chukchi Sea. The greater part of the Chukchi Sea within 190 kilometers of the cost is only from 15 to 30 meters deep.

OTHER ARCTIC SEAS

The Norwegian and Greenland Seas are bounded on the west by the Greenland continental shelf and on the east by the Norwegian, Barents, and Svalbard continental shelves. Large areas of these shelves are deeper than 180 meters and the depths of the edges vary greatly. The East Greenland shelf north of the Denmark Strait is generally broad (100 to 275 kilometers) but cut by many troughs. South of the Denmark Straits the Greenland shelf narrows to about 40 kilometers. The Norweigian shelf is 80 kilometers to 225 kilometers wide in the south and central parts but narrows to 16 kilometers off Lofoten. The continental shelf around the Svalbard archipelago ranges from 15 to 65 kilometers outward from the islands and extends south and eastward into the Barents Sea. Around Iceland the continental shelf is very narrow in the south but widens up to 130 kilometers in the west and north and to around 80 kilometers in the east.

The two dominant current systems in this region are the northern arms of the Gulf Stream and the cold Arctic water flowing southward. In the northeast Atlantic the maximum temperature difference between these water masses is about 10° C. which is generally considered too small for ocean thermal power development. In any event, if this marginal temperature differential could be exploited as an energy resource, it would require technological development and the selection of refrigerants to operate in a lower temperature range than those systems now being investigated.

The west side of Greenland is bordered by Baffin Bay and the Davis Strait, while to the southwest lies the Labrador Sea. The Robeson Channel, the northernmost channel separating Canada from northwestern Greenland, is only 16 kilometers wide at the narrowest point. Hudson Bay is a continental sea with an averaged depth of about 90 meters. Tidal ranges in Hudson Strait are high (6 to 12 meters) and approach 18 meters on the west side of Ungava Bay off the southern entrance to Hudson strait.

On the Pacific side the northern half of the Bering Sea is a continental sea with few areas deeper than 90 meters. In contrast, the southern half of the Bering Sea is oceanic with depths in excess of 3,000 meters. The Sea of Okhotsk is bordered by continental shelves up to 160 kilometers wide in the east and 320 kilometers in width in the north.

LAND AREAS

TOPOGRAPHY

The topography of an area is developed by the modifying effects of surface processes such as glaciation and erosion on the underlying geologic structures. Very generally, the basic geologic structures of the continents surrounding the Arctic Ocean are similar and consist of stable shield areas overlain in part and surrounded in part by flat-bedded plains and plateaus separated by folded mountain regions. The Canadian-Greenland Shield is roughly saucer-shaped with the center of the depression overlain by younger sediments and occupied by Hudson Bay and Foxe Basin. The rim is highest along the eastern margin from Ellesmere Island to northern Labrador with peaks reaching heights of 1,800 to 2,100 meters (6,000 to 7,000 feet). The western margin is lower but produces a conspicuous scarp where it overlooks the Mackenzie lowland. Most of the lowland shield area has a relief of less than 60 meters or about 200 feet and is covered by muskeg, scattered rounded rock outcrops and ridges separated by glacial deposits, and numerous lakes.

Greenland is shaped like an elongated basin with its major axis lying north-south. The weight of the ice sheet which covers five-sixths of the island has depressed the earth's crust such that the northern interior of the island lies 244 meters (800 feet) below sea level. The rim of the basin is highest in the east where it reaches 3,700 meters (12,000 feet) in the Gunnbjorns Mountains. The central ice sheet reaches 3,200 meters in elevation. The fiords in East Greenland are among the largest and deepest in the world.

Both Iceland and Jan Mayen are volcanic in origin consisting primarily of lavas, tuffs, and the sands derived from them. The fiords of Iceland are the typical result of glacial deepening and widening of river valleys. The highest elevation on Iceland is 2,119 meters and many peaks exceed 1,000 meters. The major landform on Jan Mayen is the volcanic cone of Beerenberg rising 2,280 meters above sea level.

The Svalbard Archipelago consists of the major island of Spitsbergen as well as Nordaustlandet to the northeast and many smaller islands. More than half of Spitsbergen and three-fourths of Nordaustlandet are covered by glaciers and ice caps. Spitsbergen is deeply incised by fiords, the greatest of which is Isfjorden (Ice Fiord) over 100 kilometers long. A striking coastal feature is a low foreland called a strandflat which varies in width from 200 meters to 10 kilometers. The highest mountain in Spitsbergen is in the northeastern part of the island and rises to over 1,700 meters. In general, the Arctic islands in the North Atlantic tend to be more mountainous in the west and plateau-like and often ice-covered in the center and east. The upland areas are deeply dissected and the lower valleys drowned to produce fiords.

The greater part of northern Scandinavia is composed of a part of the Scandinavian or Baltic Shield. The highest elevations are generally found near the Norwegian-Swedish border, sometimes reaching over 2,000 meters. Rivers flowing from the drainage divide into the Atlantic are generally short and turbulent and the coast is dissected by numerous fiords. In contrast, the drainage slope toward the Gulf of Bothnia is much more gradual and the rivers flow in wide valleys often containing long, narrow lakes. The northern part of Scandinavia, eastward to Russia, is of rolling relief generally between 300 and 450 meters above sea level but with steep sea cliffs leaving little room for coastal settlements.

The Eurasian Arctic regions are varied but in general consist of several large upland areas separated by wide depressions. The same topography of northern Scandinavia continues across Kolskiy Poluostrov and Karelia declining in elevation in the vicinity of the White Sea. The land is covered with innumerable lakes, small streams, peat bogs and glacial deposits. Lowland tundra areas extend eastward to the Urals except where they are interrupted by low hills. The general terrain is marshy, with muskeg bogs and deep peat soils.

The Urals are a hilly upland having distinct glacial landforms in the north including hanging valleys, tarns (small steep sided glacial lakes) and ice abraded rocky areas. The highest peak (2,440 meters) is about 340 kilometers (210 miles) inland from the coast. The eastern slopes are generally more gentle than the western. The Urals structure continues into the sea forming Novaya Zemlya, a massive insular land barrier that separates the Barents and the Kara Seas.

Zemlya Frantsa Iosifa is an archipelago of several hundred islands on the northeast margin of the Barents Sea between 80° and 82° N Lat. and 45° and 65° E Long. The islands are largely igneous in origin and have been heavily glaciated. Over 80 percent of the land is ice covered, and in some localities small ice shelves have formed.

The west Siberian lowlands are a monotonous marsh-covered, poorly drained tundra landscape broken by occasional terraces and low moraines. From this lowland area two major river systems, the Ob and the Yenisey flow northward into the Kara Sea through long estuaries and bays.

The Laptev and East Siberian Seas are bordered by the extensive lowlands of northern Siberia which reach far inland to the Central Siberian Plateau, except in some areas where the highlands extend nearly to the coast. Numerous rivers flow northward through the area, the largest, from west to east, are the Khatanga, Anabar, Olenek, Lena, Indigirka, and Kolyma. The northern Siberian lowlands extend eastward from the lower Yenisey River, where they merge with the west Siberian lowlands, to the Kolyma River. They form a belt approximately 2,100 kilometers long and up to 1,000 kilometers wide but narrowing to 10 kilometers in areas where uplands approach the sea. The lowlands are underlain by continuous permafrost and contain large quantities of ground ice. In some areas, shallow lakes cover more of the surface than dry land; and in the summer much of the lowland is impassable to surface travel.

In contrast to western Siberia, the mouths of most of the rivers of northern Siberia have formed deltas rather than estuaries. The

Lena River is more than 3,200 kilometers (2,000 miles) long and has the third largest delta in the world. East of the Lena River a large group of low islands called Novosibirskiye Ostrova (New Siberian Islands) separates the Laptev and the East Siberian Seas. In general, most of northeastern Siberia is mountainous.

Most of Alaska along with the Yukon Territory of Canada are within the Western Cordillera physiographic province of North America. The Cordillera in this region consists of parallel mountain ranges separated by plateaus and lowlands. The major river draining this region is the Yukon which is navigable five months during the summer by steamships and tugboats for a distance nearly 2,900 kilometers (1,800 miles) upstream.

The Arctic Coastal Plain slopes very gently from an average elevation of 180 meters near the southern margin to sea level along the coast. The plain consists of ice, sand, and silt with ice volumes as high as 70 percent in the upper 6 meters of sediment. The plain is poorly drained with countless thaw lakes, marshy areas, and braided stream channels.

GEOLOGY

Three ancient shield areas are the predominant regional geologic features surrounding the Arctic Ocean. These Precambrian shields, consisting primarily of granites and gneises, are the Canadian-Greenland Shield in the Western Hemisphere, the Baltic or Scandinavian Shield in northern Europe, and the Angara Shield in north-central Siberia. The margins of these shields are generally buried under younger sediments of Paleozoic and Mesozoic age. In the case of the Angara Shield the younger sediments reach great depths and have experienced much faulting. Between the shield areas are orogenic belts of strongly folded sediments which appear as mountain ranges in several areas. More recent sediments of Tertiary and Quaternary age form the coastal plains of northern Alaska, the deltas of the Mackenzie, Yukon, and Siberian rivers and the west Siberian lowland. Active volcanic belts of the circum Pacific tectonic zone extend into the Arctic on the Pacific side and the volcanic belt running along the Mid-Atlantic Ridge extends through Iceland.

ENVIRONMENTAL CONSIDERATIONS OF RESOURCE DEVELOPMENT

The major Arctic resource development most often discussed because of its size and importance is the production of oil and gas from the north slope of Alaska. The Alaska pipeline now under construction was delayed for several years because of concern for protection of the environment. Similarly, the possible environmental damage of a proposed gas pipeline to the north slope is now being investigated.

Oil exploration in Alaska began in 1902 with the drilling of two wildcat wells. The first drilling on the north slope began in 1944 by U.S. Navy. Early exploration and development in uninhabited areas where the natural environment is sensitive to disturbance has left its mark. Disturbance of the tundra surface causes seasonal melting of the underlying permafrost causing subsidence. Due to the slow revegetation of the tundra, once this process begins, tractor trails made 20 years previously are found to still be subsiding. For this reason roads are now built on thick gravel pads to insulate the permafrost and off road travel in the summer is prohibited. However, concern has been raised that gravel road pads may have altered some drainage patterns and that removal of the gravel from stream beds possibly results in the destruction of habitat for food chain organisms and spawning areas for fish. Considering the immenseness of the Arctic, however, it would appear that even if effects such as these are demonstrated to have a significant negative local impact, they would hardly have a significant impact on the general ecology of the entire north slope.

Other concerns being voiced about Alaska's pipeline road are that its ultimate long term impact may be greater than that of the pipeline itself. If the road were opened as a public highway and development allowed along it, this would undoubtedly be true. As Alaska's governor, Jay Hammond, was reported as saying at a recent conference of the National Audubon Society and the Sierra Club in New York, "Access is going to have to be restricted. . . . It's unfortunate that it's being built, but that was a decision taken under a previous administration. Maybe what we need is a State refuge [surrounding the road] 10 miles wide and 800 miles long." [2]

Certainly numerous examples of the social and environmental impacts resulting from the westward expansion of settlers in the lower 48 States can be cited. The question that arises is one of a value judgment. Is development in a particular area more beneficial to more people than preservation of the area? Would it have been better to have restricted access to the Oregon trail or to have prohibited its development? Obviously when development is necessary or desirable traditional ways will change, but development can proceed with a sense of social and environmental responsibility.

Oil spills may create more serious environmental problems than the construction activities connected with oil and gas production and transportation. There is no fail-safe technology and oil spills are likely to occur despite the use of the best technology available. There are indications that spills in polar regions may be of greater concern than elsewhere for a number of reasons. One reason often cited is that evaporation would be slower at colder temperatures which, in the case of a marine spill, would allow more of the oil to enter into solution and remain longer in the marine environment even though the solubility of the petroleum hydrocarbons is lower at colder temperatures. In the case of a spill on permafrost or ice, the increased absorbtion of solar radiation would initiate melting. Another reason for believing that the effects of oil spilled into the Arctic would be longer lasting and generally more serious than in warmer climates is that the rate of bacterial degradation and other processes of weathering are comparatively slower at very cold temperatures. Furthermore, the marine biota of polar regions are generally long-lived, have low reproductive potentials and do not have wide ranging dispersal stages, which would suggest that recovery of a spill area through recolonization would be relatively slow. Further ecological observations are in progress in an attempt to shed more light on the possible biological impacts.

While estimates of the persistence or residence time of oil in the ocean are speculative it has been suggested that oil entering the Arctic

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[2] Alaska's Pipeline Road: New Conflicts Loom. Science, v. 189, July 4, 1975, p. 30–32.

Ocean may remain there for periods as long as 50 years.[3] This is in contrast to other estimates of an average residence time of 2.4 months for petroleum in the world's oceans, and observations that the amount of tar (the most persistent petroleum fraction) found in the oceans is approximately equal to one year's estimated input.[4]

Photo by James E. Mielke

Oceanographic research in Lake Tuborg, Ellesmere Island, N.W.T., Canada. Research in the polar regions is contributing to better understanding of the environmental factors that may affect or be affected by resource development.

The possibility of large scale thermal climatic impacts from large amounts of oil spilled into the Arctic Ocean has also been raised.[5] This concern builds on the fact that oil will greatly reduce the albedo or reflectivity of an ice surface and reaches the assumption that this could significantly change the heat balance in the Arctic Ocean and cause widespread melting of the ice pack. Several mechanisms have been proposed that could lead to a hypothetical impact of this scale. Other investigators have pointed out that the amount of oil needed to accumulate on ice surfaces at any one time and the surface area of the oil-covered ice needed in order to produce a possible large-scale climatic effect are far greater than that likely to occur.[6]

Intentional climate modification in the Arctic with a side benefit of power production or to enhance industrialization and development near mineral resources in the Arctic regions is another environmental consideration that bears mention. Schemes of this nature have repeatedly been proposed by Russian scientists primarily in the hope of improving the cold arid climate over Siberia where frosts frequently destroy crops in the north and droughts are common. The Arctic basin is an important source region for air masses that adversely affect Russia's agricultural lands. One proposal for global weather modification proposed by a Soviet scientist is to dam the Bering Strait to prevent Pacific water from entering the Arctic Ocean and to pump water from the Chukchi Sea through the dam.[7]

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[3] Campbell, W. J. and S. Martin. Oil and Ice in the Arctic Ocean: Possible Large-Scale Interactions, Science v. 181, July 6, 1973, p. 56–58.

[4] Butler, J. N. Pelagic Tar. Scientific American, June 1975, p. 90–97.

[5] Campbell and Martin, op. cit., p. 56–58.

[6] Ayers, R. C. Jr., H. O. Jahns and J. L. Glaeser. Oil Spills in the Arctic Ocean: Extent of Spreading and Possibility of Large-Scale Thermal Effects. Science, v. 186, November 29, 1974, p. 843–845.

This supposedly would create a flow of warm water from the Gulf Stream through the Arctic and out the Pacific side without the counter currents that now exist. The hypothesis then is that melting of the Arctic ice would occur leading to a mild world wide climate similar to the Climatic Optimum that occurred 4,000 to 6,000 years ago.

Other Soviet proposals involve diverting some of the major northward flowing Siberian rivers, of which the Pechora, Ob, Irtysh, and Yenisei have been mentioned. The water would be used for navigation, power generation, irrigation of vast tracts of arid land, and to fill the shrinking Aral and Caspian Seas. One project under the so-called Davidof Plan would divert 300 cubic kilometers of water annually from the Ob River to Kazakhstan and Central Asia. The dam for this diversion would create a lake having an area of 250,000 square kilometers. Such projects would substantially reduce the flow of fresh water to the Arctic which helps maintain the polar ice pack. Once melted, there is concern that the reduced temperature difference between the pole and the tropics would change world-wide rainfall patterns, the strength of the jet stream, and the spacing between low-pressure weather systems, and thus the economies of many nations. Although some Soviet writers have said the really large developments are still far in the future, there reportedly are accounts that work on diversion of the Ob and Yenisei has already begun.[8] While Soviet ecologists and conservationists are concerned about the climatic hazards, the prevailing tone of discussion by Soviet developers seems to be that large-scale southward diversion of Siberian rivers is essential and inevitable. One might also speculate that reducing the polar ice pack could be of strategical interest to the Soviet Navy.[9]

In May 1972, the United States and the U.S.S.R. signed a five-year Agreement on Cooperation in the Field of Environmental Protection. Although the program has been criticized for inadequate funding, bureaucratic delays and disagreements within and between both countries, and coordination and communication difficulties, there is some evidence that it is now advancing.[10] One area of mutual interest where reciprocal research visits are occurring is in the influences of environmental changes and polar areas on climate. Another area of joint activity is protection of northern and Arctic ecosystems with special focus on environmental problems of oil and gas pipeline construction in Alaska and Siberia.

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[7] Borison. P. M. Global Weather Modification and the Arctic Basin. The Northern Engineer. v. 3, n. 1971. p. 7–9.

[8] Nace. R. L. Environmental Hazards of Large-Scale Water Developments. Department of the Interior. Raleigh. N.C., July 1972. 25 p.

[9] Horton. A. M. Weather Modification A Pandora's Box. Air Force Magazine, February 1975. p. 36–40.

[10] Seltzer. R. J U.S.-Soviet Environmental Work Advances. Chemical and Engineering News, February 2, 1976, p. 20.

COAL

ALASKA

HISTORY OF COAL DEVELOPMENT IN ALASKA

The first coal mine in Alaska was opened by the Russians in 1855 at Port Graham on the southwest tip of the Kenai Peninsula. The mine was operated until 1867 when the United States took possession of Alaska. Intermittent coal mining took place at several localities along the Yukon River and near the southern coast until 1916 when sustained production began with the completion of the Alaskan Railroad from Anchorage to the Matanuska coal field and to the Nenana field in 1918. Strip mining began in Alaska in 1943 and is now the only mining method in use in the state. Coal production continued to increase until 1953 when oil and gas fields in Cook Inlet were developed. Fuel requirements for the military in the Anchorage area shifted

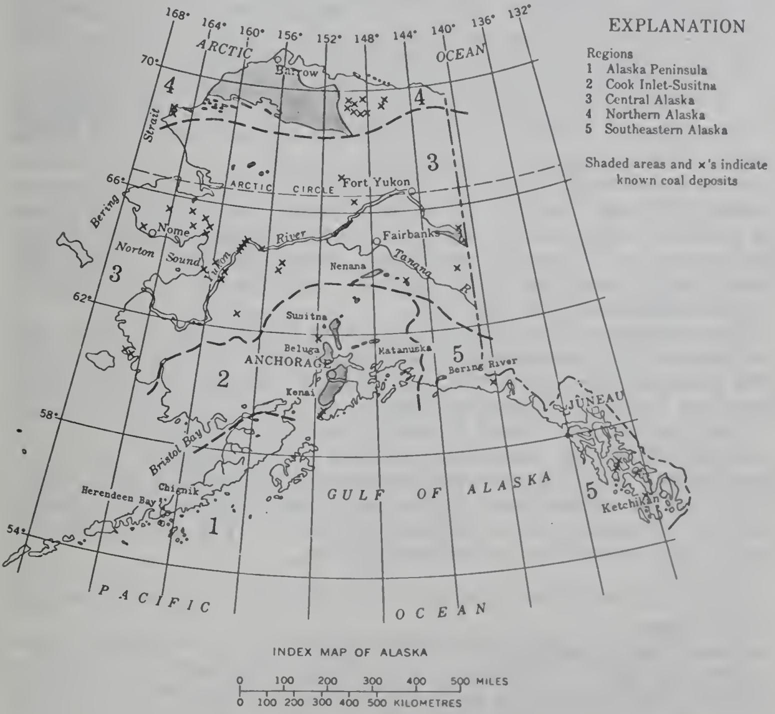

FIGURE 4.—Coal regions of Alaska.

from coal to oil in 1967 causing a decrease in production. However, the increased demand for electric power in the Fairbanks area has offset the decline and coal production has started to increase. Because Alaskan coal is produced primarily for a nonindustrial domestic market, yearly fluctuations in production are directly related to the severity of the winter. In 1969–1970 the Golden Valley Electric Association (GVEA) constructed a mine-mouth power plant in the Nenana field 120 kilometers southwest of Fairbanks with a transmission line to Fairbanks. Other mine-mouth generating plants are planned.

RESOURCE POTENTIAL

Coal is found throughout many parts of Alaska (Fig. 4), ranging from small isolated occurrences to very extensive coal fields. The coal deposits in Alaska range in age from Carboniferous to Tertiary, and grade from lignite through anthracite. The principal coal fields are in five major regions: (1) the northern Alaska region along the North Slope of the Brooks Range; (2) the central Alaska region, including the Nenana coal field on the north flank of the Alaska Range and scattered occurrences on the Seward Peninsula and in the Yukon and Kobuk River basins; (3) the Cook Inlet-Susitna region, including the Broad Pass, Susitna, Matanuska, and Kenai coal fields; (4) the Alaska Peninsula region, including the Herendeen Bay, Unga Island, and Chignik coal fields; and (5) the southeastern Alaska region, including the Bering River coal field and several minor localities on the mainland and on islands of the Alexander Archipelago.

Alaska's identified coal resources are conservatively estimated by the U.S. Geological Survey at more than 130 billion tons consisting of more than 19 billion tons of bituminous coal and nearly 111 billion tons of subbituminous coal and lignite.[1] The Survey estimate suggests that on the average 50 percent of this may be recoverable by present mining methods. The U.S. Geological Survey report states, "Because of insufficient data no estimates are given for many parts of Alaska that are known to contain significant amounts of coal."[2] Other estimates suggest there may be at least this much more in mineralogically unexplored areas of the state.[3]

One estimate projects the coal resources in the Cape Lisburne area alone to be 202.5 billion tons in bituminous coal.[4] Total identified U.S. coal resources are estimated at 1,581 billion tons, and those of Alaska based on the U.S. Geological Survey estimates rank fourth in the United States behind North Dakota, Montana, and Illinois.

Hypothetical coal resources in Alaska are estimated at 135 billion tons making the total estimated resources in Alaska 265 billion tons.[5] Hypothetical resources are defined as undiscovered mineral deposits, whether of recoverable or subeconomic grade, that are geologically predictable as existing in known districts.

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[1] Barnes, F. F. Coal Resources of Alaska. U.S. Geological Survey Bull. 1242–B, 1967, 36 p. plus map.

[2] Ibid., p. B9.

[3] U.S. Federal Field Committee for Development Planning in Alaska. Economic Outlook for Alaska. Anchorage, 1971, 392 p.

[4] Reed, J. C. Minerals Development in Arctic Alaska Through 2000. Arctic Institute of North America, Research Paper No. 63, Washington, D.C., 1973, p. 22.

[5] Averitt, Paul. Administrative Report—Pipeline Gas from Coal in the United States. National Gas Survey, v. 5, Federal Power Commission, 1974, p. 78.

RESERVES

The northern coal field covers an area of about 150,000 square kilometers extending northward from the northern foothills of the Brooks Range to the Arctic coast and eastward from Cape Lisburne at least as far as the Itkillik and lower Colville Rivers. The northern coal field contains 92 percent of Alaska's coal resources and ranks with major coal deposits in the world. The known strippable reserves rank this field as second in the United States in subbituminous coal, with a reserve of 5 billion tons, and third in bituminous coal, with more than 2 billion tons.[6] The coal beds in the northern field occur throughout the Corwin formation which has a measured thickness of over 4,570 meters. The thickest coal beds are in the lower sandstone and bentonite members.

The Susitna field contains the largest reserve of coal recoverable by strip mining in southern Alaska. The southern portion of this area near Cook Inlet, is also called the Beluga field. The coals are found in the Kenai Formation which is relatively flat-lying. In many sections the coal beds are more than 15 meters thick under less than 37 meters of cover. The sulfur content is less than 0.2 percent. The favorable stripping ratio, low sulfur content, nearness to tidewater, and accessibility to a labor supply are factors which contribute to an active leasing and exploration program by private companies in the Beluga field.

The Nenana field coals are low in sulfur, 0.1 to 0.4 percent. The Nenana field contains 457 million tons that can be recovered by strip mining. Coal production in this field will probably continue to increase and supply GVEA and the Fairbanks area.

COAL MINING PROBLEMS IN ALASKA

The present market for Alaskan coal is the interior region around Fairbanks and scattered thermal electric power plants. Because of this complete dependence on local markets demand is greatest during the winter months when coal is used primarily for heating. This means that maximum production occurs under the combined adverse conditions of low temperature and limited daylight. Cold and darkness decrease efficiency in mining. Equipment operators have the benefit of heated cabs but outdoor workers have to wear bulky clothing and take precautions against frostbite. Work requiring manual dexterity means removing mittens and taking time to warm up afterwards.

Starting equipment under extreme conditions can be difficult and maintenance is costly. Parts must be stockpiled and replacements from the lower states take time to arrive. Equipment can be kept running constantly or stored in heated buildings but both remedies increase operating costs. Expensive special arctic lubricants are necessary, and diesel fuels must be diluted with lower pour-point light distillates which appreciably reduce the effective power of trucks, bulldozers, etc.[7]

Another problem of mining coal in the Arctic is the accumulation of coal dust in the tipple (area where the mine output is dumped, screened, and the coal is prepared for market). With temperatures well below freezing it is impossible to wash down the tipple, and dust collectors are never 100 percent effective. In extreme cold weather, the fire danger is compounded by the possibility of frozen water lines.

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[6] Conwell, C. N. Alaskan Coals. Transactions Society of Mining Engineers, AIME, vol. 252, Sept. 1972, p. 279–282.

[7] Hall, W. B., Polar Mining. Mining Congress Journal, July 1975, p. 46–51.

Other problems related to cold weather are the removal of snow from coal cars, and the thawing and refreezing of coal in bunkers.[8] Pit walls may also collapse during the spring thaw.

Despite the adverse conditions, the winter months have their advantages for mining. Within the pits, foot and highwalls stabilize. Vehicles can move more easily over the frozen ground than over mud and tundra. Drill rigs are often moved into position for summer exploration during the winter "freeze-up". Despite the difficult operating conditions, coal production in Alaska compares quite favorably with the lower 48. The average tons of coal produced per man-day In Alaska is 35.52 whereas the national average is 34.64 tons.[9]

COAL LEASES AND PROSPECTING PERMITS IN ALASKA

Essentially all coal deposits, or likely areas for coal to be found, in Alaska are on Federal or state lands to which the appropriate leasing laws apply. The Federal coal lands are under the administration of the Bureau of Land Management in the Department of the Interior. Coal prospecting permits are granted for a period of two years upon submission of the $10 filing fee and a yearly rental of $0.25 per acre. In addition, the applicant must furnish a personal or corporate surety bond conditional upon compliance with all the terms of the prospecting permit. No permit may cover an area larger than 2,560 acres and no permit holder may retain more than four permits or 16 square miles. Only coal necessary to determine the value of the deposit may be removed, otherwise a coal lease must be obtained.

A coal lease on Federal land is subject to the same annual rental fee per acre and, in addition, a royalty payment based on a minimum annual production. For a noncompetitive lease, payments do not begin until the sixth year of the lease. In areas where commercial coal deposits are known to exist, the Federal government may divide the land into workable units and offer the leases on a competitive basis.

State coal lands are administered by the Division of Lands, Department of Natural Resources, Anchorage. Prospecting permits are issued to U.S. citizens or corporations for a period of two years upon payment of a $20 fee and submission of an outline of the method of exploration. There is an acreage limitation and leases and permits for more than an aggregate of 46,080 acres may not be held at one time with the exception that an additional 5,120 acres can be leased if it can be shown to be economically necessary to carry on business or in the public interest. Coal leases escalate from a rental of $0.25 per acre for the first year to not less than $1.00 per acre after five years and not less than $0.05 per ton royalty for coal mined and marketed. Mining plan must be approved to assure the adequate conservation of coal and land. A surety bond must also be posted to guarantee that the land will be restored to a condition that conforms to the surrounding area and any remaining coal will be covered to prevent it from becoming ignited.

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[8] Conwell, op. cit., p. 281.
[9] Ibid., p. 281.

SHIP TRANSPORTATION OF ALASKAN COAL

The cost of transportation is the key to development of Alaskan coal. The ultimate utilization of the immense coal resources of northern Alaska will depend on the development of markets to which the transportation costs will be competitive with other sources of supply. Whatever transportation system is considered, it will almost certainly have two components: land and water transport. The land component will extend from wherever the coal is mined in the northern field to a port facility on the Pacific or Arctic Oceans or on the Chukchi Sea. Ports on the Arctic Ocean or Chukchi Sea would be closed by ice in the winter so some transshipment point at an ice free port, such as Dutch Harbor in the Aleutian Islands, would probably need to be developed where coal could be stockpiled in the summer in order to provide year round market delivery.

The location of the port facility will determine which areas can be economically mined. Year-round shipment from the port of Seward would probably utilize the existing Alaska Railroad to Fairbanks and the Nenana coal field and extension northward to the eastern part of the northern coal deposits. Shipments from ports on the Chukchi Sea or Arctic Ocean would promote mining in the western part of the northern coal field nearest the ports. A May 1973 study by the University of Alaska, entitled *Transportation Economics of Coal Resources of Northern Slope Coal Fields, Alaska*, determined that at a production rate of 15,000,000 tons per year, coal up to 320 km (200 miles) from a harbor site could be transported to Japan at less than $10.00 per ton.[10] At a lower production rate of 5,000,000 tons per year, the overland distance cannot exceed 190 km (120 miles). The overland distance which the coal can be transported economically is sensitive to the market price, mining cost, profit and shipping cost. The same study found that the costs of transporting North Slope coal to Japan via a port on the Pacific Ocean (Seward) are too high to be economically feasible if the coal deposit must support the transportation network.

Shipment of coal from ports on the Chukchi Sea or Arctic Ocean would not be possible during the winter months without extensive measures to combat the ice. Such measures would probably include ice-breaking bulk carriers and ice breaker support, both of which would raise shipping costs considerably. Ships passing through the Bering Strait would encounter pressure ridges of ice up to 6 meters in height. A 1968 Coast Guard study concluded that "travel through the Bering Strait in the event of closed leads is impossible without passing through pressure ridges." [11] The Soviets make limited use of ice breakers to extend the shipping season to northern Siberian ports from 2½ months to 4 months.

Other problems of winter shipping in the Arctic requiring new and innovative technology would be the construction of harbors, piers, and terminal facilities. The northwest coast of Alaska is an area of extreme ice activity. There are no natural harbors along the Alaskan coast north of the Seward Peninsula and water depths of 18 meters are not reached less than three miles from shore. At Prudhoe Bay, cargo is transferred from ocean barges to lighter barges 10 km from shore. The information available indicates that bedrock is at or near the surface of the seabottom along the northwest coast of Alaska. Consequently, excavating an artificial harbor or channel to the coast for large ore carriers would be very expensive. The use of a nuclear device for this purpose has been considered but serious ecological consequences would probably preclude the use of this method in all but a national emergency. It is doubtful that the financial returns from the coal deposits alone could carry the cost of constructing an artificial harbor by conventional methods.[12]

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[10] Clark, P. R. Transportation Economics of Coal Resources of Northern Slope Coal Fields, Alaska M.I.R.L. Report No. 30, Univ. of Alaska, Fairbanks, 1973, 134 p.

[11] U.S. Department of Transportation, U.S. Coast Guard. Polar Transportation Requirements Study Report, Nov. 1968, 3 v.

Among the alternatives to constructing an artificial harbor are building a pier out to deep water or constructing an artificial island. A pier extending out to deep water would have to withstand severe ice pressures. Although it may be possible to design and construct such a pier of steel and/or concrete, an earth and gravel filled pier would probably be less expensive. A cost estimate of constructing a rock and gravel pier in the Chukchi Sea made in 1973 was over $20 million.[13] An artificial island could be constructed in deep water and lighters used to transport the coal from shore. The island would still be subjected to wave and ice erosion and additional handling and equipment would be required with the use of lighters. The initial cost of constructing an artificial island would also be high.

Other possible alternatives not requiring such high construction costs would involve loading the ore carriers moored in open water. One means of accomplishing this is by the use of lighters as are presently employed for unloading supplies at coastal villages in northwestern Alaska. However, this system would not be very practical for transferring large amounts of coal because of the additional ship waiting time required and the difficulties in transferring coal from barges to the ship in open water. Waiting time could be reduced somewhat by mooring a number of filled barges in deep water in anticipation of the ship's arrival.

Another possible coal loading method would be the use of a slurry pipeline from shore to a moored vessel in deep water. In a slurry loading system, the ore slurry is drawn by a floating suction dredge from a large slurry pond on shore and pumped to the ship by a moored floating pump (Fig. 5). Slurry loading systems have been developed for iron ore and other minerals and long slurry pipelines have been designed for coal transportation but none of these have been adopted to polar regions. A slurry system designed for the Arctic would have to consider:

1. Slurry ponds would freeze in the winter preventing year round loading by this method unless a way could be found to keep the pond open.
2. Pipelines may be damaged by ice gouging if left submerged on the ocean bottom during the winter months, and summer storms would pose a problem for a floating pipeline.
3. Coal is less dense than iron ore and would settle more slowly, hence, loading by slurry pipeline would take longer and tie up more ship time or else unsettled fines would have to be returned to shore by another pipeline.

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[12] Clark. op. cit., p. 44.
[13] Ibid., p. 104.

The estimated cost of a slurry loading system for the northern coal field of Alaska was $5 million in 1973.[14]

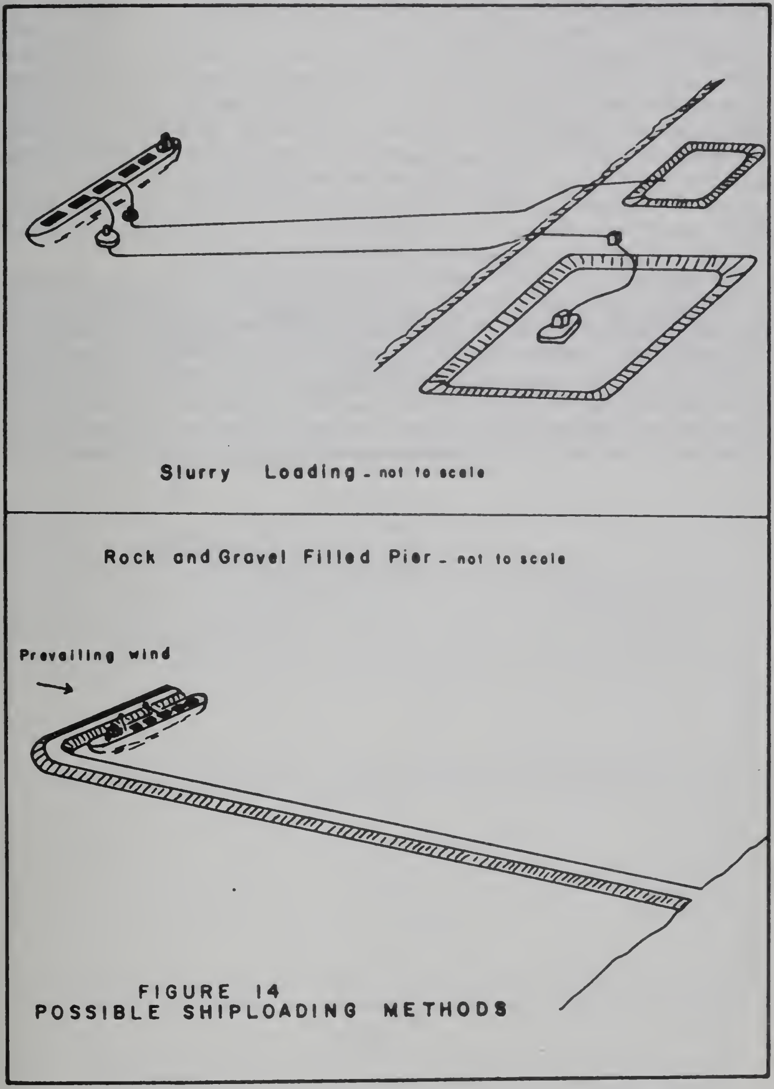
Slurry Loading - not to scale
Rock and Gravel Filled Pier - not to scale
Prevailing wind

FIGURE 14
POSSIBLE SHIPLOADING METHODS

FIGURE 5

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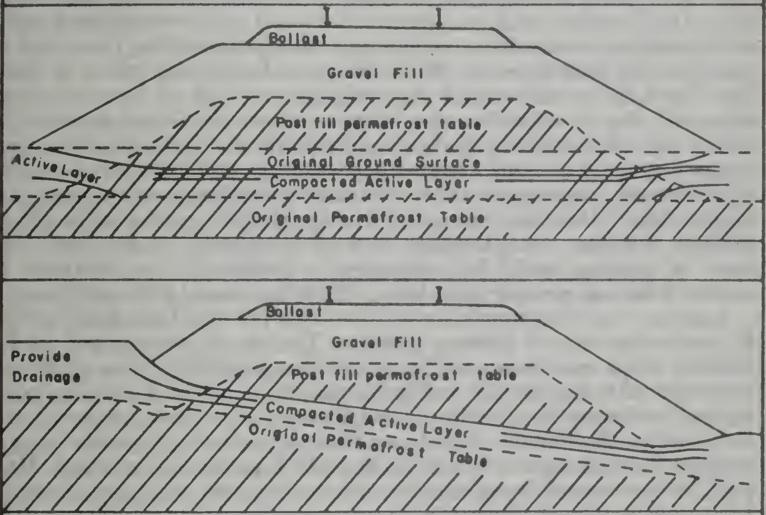
[14] Ibid., p. 117.

Source: Clark, op. cit., p. 47.

LAND TRANSPORTATION OF ALASKAN COAL

Several types of land transportation systems could be developed in the Arctic depending on the distances involved, costs of construction, and practical transporting capacity needed. The most widely used method of transporting coal overland today is the railroad. Several railroads have been built in arctic and subarctic areas. In Alaska, the Seward Peninsula Railroad and the Copper River and Northwestern Railroad near Valdez are no longer in operation. However, the Alaska Railroad which extends from Fairbanks to Seward and the White Pass and Yukon Railway which operates between Whitehorse, Yukon Territory and Skagway, Alaska are still operating. Other railroads operating in northern areas of Canada are the Labrador Ungava Railway, the Great Slave Railway, and the Hudson Bay Railway.

Construction of a railroad over permafrost requires large amounts of fill. The fill material serves as the railroad bed and as insulation to prevent thawing of the permafrost (Fig. 6). If the permafrost were to thaw, uneven settling of the railroad bed would result. In northern areas railroads are generally built along the sides of hills rather than in valley bottoms which are likely to flood during the spring run-off. Since water contact with permafrost causes thawing, drainage is an important consideration for railroad construction in permafrost areas.



PROFILES OF TRACK CONSTRUCTION IN PERMAFROST

FIGURE 6

Source: Clark, op. cit., p. 26.

Railroad construction costs on the order of $1.8 million per mile have been projected for Arctic regions.[15] While these costs would vary from one location to another they would generally be much higher than in southern areas. Among the difficulties that have been mentioned that lead to higher costs are: (1) transportation costs for supplies and materials from southern areas, (2) severe climatic conditions causing lower labor and machine efficiency, (3) large volumes of fill required, and (4) inadequate labor supply. Although higher in cost to construct than other land transportation systems, railroads offer greater flexibility than systems such as conveyor belts and pipelines and can easily accommodate increased tonnages and backhaul traffic. The costs of transporting coal from the North Slope to Fairbanks, where it could join the Alaska Railroad to Seward, are too high to be economical, even with the use of unit trains, if the northern field must support the entire cost of extending the railroad. However, if construction were supported by State and Federal governments and costs were ameliorated by other users, such as oil producers and other developments that might occur along the route, the transportation economics might be entirely different. Rail haulage to ports developed on the northwest coast of Alaska would be economically feasible if the distances involved were not greater than 160 to 320 kilometers (100 to 200 miles).

Another land transportation system with potential for development of north slope coal is a slurry pipeline. The use of slurry pipelines for loading ships has been mentioned but the possibility also exists for their use in transporting coal from the mine site to a loading point on the northwest coast, or for a long distance pipeline to transport coal to a port on the Pacific coast. Long distance coal slurry pipelines have already been constructed, such as the 440 kilometer long Black Mesa pipeline between Arizona and Nevada, and several others much longer have been proposed. The main advantages of a slurry pipeline are low operating costs and low material losses. Because a pipeline is a closed system, environmental contamination from dust loss is minimal.

A number of factors such as particle size, pumping velocity and solids concentration influence slurry pipeline design. The optimum velocity for commercial coal slurry applications has been determined to be between 0.9 and 1.8 meters per second. Solids concentrations in the range of 45 to 60 percent by weight are used in commercial coal slurry pipelines. Beyond 60 percent, small increases in concentration require disproportionately higher pumping horsepower and higher costs relative to the small gains in amount of material transported.

Another factor to consider in the operation of a slurry pipeline is the carrier fluid. Normally water is used but it would be entirely possible to use other fluids such as crude oil, depending on availability and market conditions. This point is raised because a pipeline for crude oil from the north slope is already under construction. However, slurry pipe generally has a higher carbon content than oil pipe to withstand abrasion from the solid material. On the other hand, the existing Alaska pipeline right of way could be utilized for the construction of a slurry pipeline, perhaps with the dual purpose of transporting oil, if energy considerations and resource availability warranted it. Furthermore, the scarce availability of water for a carrier fluid may place constraints on the operation of a slurry pipeline in northern Arctic areas, particularly in the winter.

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[15] Ibid., pp. 27, 134.

Year round operation of a slurry pipeline in the Arctic would require design considerations that are not incorporated in other long distance slurry pipelines. Several short distance pipelines exist in cold areas, but these are either heated or the exposure time to cold temperatures is minimal. A year-around slurry pipeline in the Arctic would have to be insulated and/or heated. The technology for pipeline construction in permafrost has already been developed for the Alaska pipeline.

Another land transportation system is truck haulage. Since each truck is a self propelled unit, labor costs and maintenance costs are high. Trucks may be practical for short distance transport but would not be economical for transporting large amounts of coal long distances. Trucking systems have the advantage of easy expansion by the addition of more road and/or more trucks. Grade limitations are not as great as for railroads in that railroads are generally restricted to grades close to 2 percent while roads can be constructed with grades of 8 percent or more. Capital costs are generally low and back haulage of supplies and equipment is easily possible. The problems of road construction in permafrost areas are similar to those noted for railroad construction.

Belt conveyors are another common method for the movement of bulk materials. A number of single flight conveyors are generally coupled to form a longer conveyer system. The length of a conveyor system appears to be unlimited, but the length of a single flight is limited by the tension rating or strength of the belt. New belts and drive concepts are being developed to permit single flight conveyors up to 80 kilometers (50 miles).[16] The advantage of longer single flights is in reducing transfer points where spillage generally occurs.

Operating a belt conveyor system in the Arctic is far more complicated than in southern areas. Pilings must be constructed to prevent shifting from freezing and thawing causing misalignment of the belt. In areas where snow and wind are severe, the conveyor must be covered to protect the bearings and prevent icing on the idlers which may cause belt run-off and spillage. Belts must be either completely heated or completely unheated as problems are greatest when freezing occurs on the conveyor. Belt conveyors have operated in temperatures below −43° C. When material is not being transported, the conveyor is run at a creep speed to prevent freeze-up.

In general, belt conveyor systems are relatively easy to operate and have low maintenance costs. Long distance systems have the disadvantage of inflexibility and they create a surface obstruction that may be objectionable.

FUTURE PROPOSALS FOR ALASKAN COAL

The ultimate utilization of the immense coal resources of northern Alaska will depend on the development of markets to which the transportation costs will be competitive with other sources of supply. Transportation of coal from the northern field would entail either land shipment to a more southerly ice-free port in Alaska or year-around ice breaking service to a northern location where a port could be developed. The coal deposits of south central Alaska still cannot compete in price or quality with other coal exporters.

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[16] Ibid., p. 35.

The markets for coal fall into two main categories, coking coal and non-coking coal. Coking coal is an essential ingredient in the manufacture of steel, whereas non-coking coal is used mainly for fuel in thermal-electric power plants. There are adequate supplies of non-coking coal in Canada and the lower 48 States to last several hundred years at the present rate of consumption. Furthermore, the Japanese Government has regulations restricting the importation of steam coal. Consequently, outside of domestic use, which is primarily being satisfied from the Nenana coal field, a market is not likely to develop for non-coking coal from Alaska unless there are other incentives. However, because of the low sulfur content of much of the Alaskan coal, a future market could develop in the lower 48 States in order to meet air quality standards despite the high transportation costs.

Three localities in Alaska have been found to have commercial potential for coking coal, the largest being the Utokok-Corwin region in northwestern Alaska where coal beds having coking characteristics underlie 3,200 square kilometers: Inferred estimates for this area range from five to eight billion short tons. In southcentral Alaska, the Bering River coal field has an area of 135 square kilometers of which about one-third has coking potential. Limited amounts of coking coal are also present in the Chickaloon coal field in the Matanuska Valley. Although much of the bituminous coal of northern Alaska is not directly suitable for coking, the U.S. Bureau of Mines has found the Cape Beaufort coals capable of producing metallurgical quality coke by blending with as little as 15 percent strongly coking coals.

At the present time Japan is the most favorable potential market for coking coal from Alaska. Japanese interest in Alaskan coal has been high for a decade, and they have financed exploration in the Bering River and northern fields.[17] Alaskan coal has a geographic advantage and, consequently, a transportation cost advantage over many of Japan's coking coal suppliers. Japan has previously expressed a need for one million tons per year of low volatile or medium volatile coking coal.[18] On the other hand, the U.S.S.R. has proposed to Japan the development of the South Yakutsk, Siberian coal field at a cost of 175 to 185 million dollars.[19] Japan conveyed its intention of importing up to 10,000,000 tons per year from this field in the late 1980's provided the quality meets their requirements.

GASIFICATION OR LIQUEFACTION OF COAL FROM THE NORTH SLOPE

Another possibility, although at this time more in the realm of future speculation, is the recovery of energy from North Slope coal through gasification or liquefaction with subsequent transport through existing pipelines serving oil and gas fields. The major part of the coal in the northern field is subbituminous and non-coking. Because of its low grade it would not likely be transported as a solid for use as boiler fuel when other deposits are closer to consumers. However, as the prices of oil and gas rise synthetic fuels of this nature become more competitive. A pipeline is currently under construction to transport oil southward from the North Slope. Several proposals are under consideration to construct a gas pipeline to the same area. Coal gasification or liquefaction plants are expensive, but they could be located at a mine site and feed into the future existing pipelines. Synthetic fuels produced from North Slope coal would still have to compete with synthetic fuels that could be produced from large coal deposits in the lower western states. It is possible that future energy needs will make this feasible or necessary.

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[17] Economic Outlook for Alaska, op. cit., p. 185.

[18] University of Alaska. Mineral Resources of Northern Alaska, M.I.R.L. Report No. 16, 1969.

[19] U.S. Bureau of Mines. International Coal Trade. May 1972.

ARCTIC CANADA

Coal is not presently included among the economically significant energy resources of Arctic Canada. A large coal field is known at Moose River in northwestern Canada, near the Arctic coast. The only Canadian coal production north of 60° has been in the Yukon Territory which peaked at an annual value of $123,675 in 1963. No production has been reported since 1968. Canada has large coal resources in its western provinces which have been largely unexploited except for export and local use since in the past it has been cheaper to import coal into the eastern provinces. As in the United States new emphasis on developing Canadian coal resources will focus on the western deposits before looking toward the Arctic.

GREENLAND

Geologically, the Greenland Shield, which is widely considered part of the Canadian Shield, is a basement complex of very old metamorphic rocks covered in certain areas with thin layers of sedimentary rocks. It is in the sedimentary basins that the mineral fuels are found. These basins are in northern Greenland and in the vicinity of Disko Island on the west coast and at the same latitude around Scoresby Sound on the east coast.

Intermittent mining of coal in Greenland has continued since the 19th century. Coal was mined for local use at Qutdligssat on Disko Island until April 1972. At that time the Danish Government decided to terminate the mining operation there due to the uneconomic nature of the mine and the inadequate local market. Production in 1970 amounted to 18,000 metric tons.

Greenland coals are relatively young and of low quality. On Disko Island and Nugssuaqua Peninsula, between the Vaigat and Umanak Fiords, there are considerable fields of Cretaceous coal, and at Scoresby Sound, on the East coast, Triassic lignite has been found. Recoverable reserves of Greenland coals are estimated at around 50 million metric tons.[20]

NORWAY (INCLUDING SVALBARD)

Except for Svalbard (Spitsbergen), Norway has no coal resources of even local significance, although a minor amount of peat is cut for fuel use (5,000 tons in 1972). All Norwegian coal production was mined by Det Store Norske Spitsbergen Kulkompani A/S (SNSK) at Longyearbyen on Vestspitsbergen. Shipments totaled 433,000 tons in 1972, with most of the coal going to the Norweigen cokeworks at Mo-i-Rana. Russian production from Svalbard is in the vicinity of 300,000 tons.

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[20] Prast, W. G. Greenland—Mines and Prospects. Mining Magazine, January 1973, p. 25–30.

The Paris Treaty of February 9, 1920 granted Norway sovereignty over Svalbard under an arrangement that recognized and preserved the established rights of the other countries involved to exploit their coal and other mineral holdings and to fish in Spitsbergen waters. Nine countries signed the treaty which came into force in 1925, and an additional 25 countries have accepted the treaty. The nine signatory countries were Denmark, France, Italy, Japan, The Netherlands, Norway, Great Britain, Ireland, and Sweden.

Much of the coal in Svalbard is fairly young, of Cretaceous and Tertiary age, and several good seams have been mined. Older Devonian coal is also found, but of relatively poor quality. Early mining operations on Svalbard were carried out by the Norwegians, Swedes, Americans, Dutch, and Russians. The Norwegians purchased the American fields at Longyearbyen in 1916 and later the Swedish mining establishments at Sveagruva on Van Nijen Fiord. SNSK is currently exploring and evaluating the Sveagruva coal deposits.[21]

Russian mining of coal on Svalbard began in 1919–1920 and increased with renewed interest in 1932. A state-run Soviet concern, Arktikugol, purchased the Dutch coal fields, including Barentsburg on the east side of Gronfjorden in Vestspitsbergen. Gronfjorden is one of the best anchorages in Svalbard, and Barentsburg is the main Soviet base for mining activities in Svalbard with an administrative center, consulate, and radio station. The Soviets are also mining coal at Pyramiden on Billefjorden and until 1963 operated a mine at Grumant on the southern side of Isfjorden, both in Vestspitsbergen.

Several coal seams are found in Devonian sediments on Bjornoya (Bear Island) located between Spitsbergen and northern Scandinavia. Mining of one of these seams has been attempted at Tunheim on the northeast coast.

SWEDEN

Sweden does not have significant resources of coal. A small quantity of coal, 10,000 tons in 1972, is produced in southern Sweden by Hoganas AB as a byproduct of clay mining. In addition, approximately 33,000 tons of peat were cut for fuel use in 1972.

FINLAND

As is typical for the Scandinavian countries, no economic resources of coal have been found in Finland. Although there is no production of coal, peat is extracted for fuel use. Peat production for fuel use reached 151,000 tons in 1972, and an additional 127,000 tons were produced for agricultural and other uses. Firewood is also a major source of solid fuel in Finland.

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[21] U.S. Bureau of Mines, Minerals Yearbook 1972,, v. III, Washington D.C., 1974, p. 630.

ARCTIC RUSSIA

RESOURCES, RESERVES, AND PRODUCTION

The coal resources of the Soviet Union are distributed among 25 coal fields, 8 large coal-bearing areas and more than 650 individual known deposits (Figure 7). Four major coal basins and deposits are found in the Soviet Arctic north of 60°. In the European Russian Arctic, the Pechorskiy Kamenougol'nyy Basseyn (Pechora Coal Basin) deposits are estimated at 262.4 billion tons of coal extending over an area of 120,000 square kilometers. The Pechora Basin is one of the major coal production centers in the Soviet Union. In the Siberian Arctic, the coal deposits in the Taymyrskiy Ugol'nyy Basseyn (Taymyr Coal Basin) are estimated at 583.5 billon tons, the Ust'Yeniseyskiy Uglenosnyy Rayon (Yenisey Coal-bearing District also called the Tungussk Region) at 221.75 billion tons, and the northern part of the Lenskiy Uglenosnyy Basseyn (Lena Coal-bearing Basin) at 2,647 billion tons.[22] The Lena coal region extends over an area of 400,000 square kilometers.

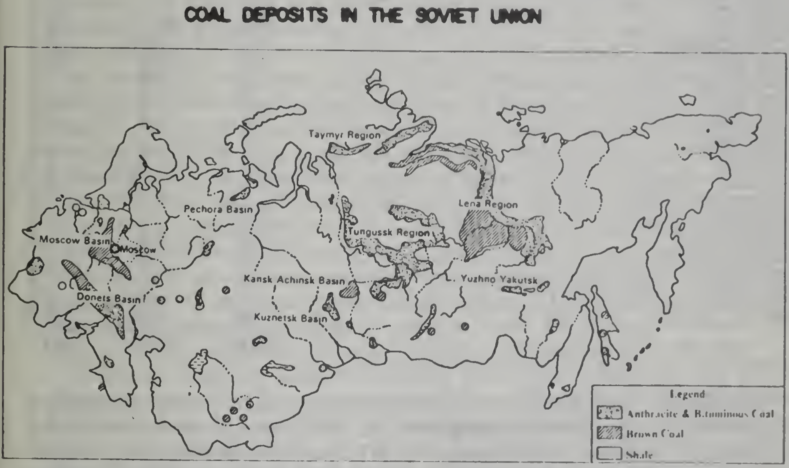
COAL DEPOSITS IN THE SOVIET UNION

FIGURE. 7.—Major coal deposits in the Soviet Union.

Total hypothetical and speculative potential coal resources of the Soviet Union are estimated at 6,800 billion tons which includes lignite resources to a depth of 600 meters. Prior to December 1969, lignite resources were estimated to a depth of 1800 meters and total resources of 8,699.5 billion tons were claimed.[23] The hypothetical potential coal resources of 6,800 billion tons represent about 55 percent of the world coal resources. However, the officially reported Soviet resources are no more than geologic prognoses and have yet to be explored. Only eight percent of their total geologically potential resources are considered to be economically minable by Soviet classification (Table 2). Approximately 85 percent of the Soviet Union's "possible reserves" including most of the high quality coal reserves are in the northern Siberian regions.

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[22] Sater, J. E., A. G. Ronhovde and L. C. Van Allen. Arctic Environment and Resources. The Arctic Institute of North America, Washington, 1971, p. 256.

[23] Strishkov, V. V., G. Markton and Z. E. Murphy. Soviet Coal Productivity: Clarifying the Facts and Figures, Mining Engineering, May 1973, p. 46.

TABLE 2.—SOVIET ECONOMIC MINABLE RESERVES ('BALANSOVYE') OF COAL AND LIGNITE BY BASIN AND CATEGORY ON JAN. 1, 1968

[In billion metric tons]

Regions, coal basins and deposits	Categories		Total
	$A+B+C_1$	C_2	
Donets Basin	40.5	16.8	57.3
Pechora Basin	8.0	6.8	14.8
Moscow Basin	5.0	2.3	7.3
Lvov-Volyn Basin	.7		.7
Dneprovsk Basin	2.6	.1	2.7
Caucasus	.4	.04	.44
Kizelovsk Basin	.6	.1	.7
Chelyabinsk Basin	.9	.04	.94
South Urals	1.3		1.3
Karaganda Basin	7.5	6.9	14.4
Ekibastuz Deposit	7.4		7.4
Maykuben Basin	1.8		1.8
Turgay Basin	6.3	.4	6.7
Kuznetsk Basin	66.2	144.4	210.6
Minusinsk Basin	2.8		2.8
Kansk-Achinsk Basin	72.0	43.2	115.2
Irkutsk Basin	7.1	13.4	20.5
Tungussk Region	1.9	3.0	4.9
Taymyr Region	.1	.6	.7
Lena Region	2.3	1.0	3.3
Yuzhno-Yakutsk	2.6	3.3	5.9
Zyryansk Basin	.2		.2
Buryat A.S.S.R.	2.4	1.9	4.3
Chita Oblast	3.2	.02	3.22
Amur Oblast	2.1	.05	2.15
Khabarovsk Kray	.8	1.2	2.0
Maritime Kray	2.5	1.7	4.2
Sakhalin Island	2.0	1.5	3.5
Magadan Oblast	1.3	3.3	4.6
Kamchatka Oblast	.07	.06	.13
Kirghiz S.S.R.	1.5	2.0	3.5
Uzbek S.S.R.	.7	.5	1.2
Tadzhik S.S.R.	.7	.5	1.2
Other	5.96	7.13	13.09
U.S.S.R. total	261.43	262.24	523.7

The Soviet classification of economically minable reserves in place (*balansovye*) includes the categories, A, B, C_1, and C_2 as follows: (A) prospected in detail and measured; (B) measured but lacking qualitative and quantitative detail; (C_1) determined by geophysical or other methods and inspection of outcrops; and (C_2) undiscovered hypothetical and speculative reserves. Total economically minable reserves are reported as 523.7 billion metric tons.[24] These catagories are comparable to measured, indicated, inferred, and hypothetical reserves in U.S. terminology. Other Soviet reserves are classified as identified, submarginal, but minable (*zabalansovye*) and are also broken down into the catagories A, B, C_1, and C_2. These reserves are not considered economically minable.

Economically minable reserves in the Soviet Arctic are 23.7 billion metric tons. Further subsurface exploration or development in the Arctic could probably raise these figures considerably. Broken down by region economically minable reserves are reported at 14.8 billion tons in the Pechora Basin, 0.7 billion tons in the Taymyr Region, 4.9 billion tons in the Tungussk Region, and 3.3 billion tons in the Lena Region.[25]

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[24] U.S. Bureau of Mines. The Mineral Industry of the U.S.S.R., V. V. Strishkov. In Minerals Yearbook 1972, v. III, U.S. Dept. of Interior, Washington, 1974, p. 842.

While no one really knows the extent of Soviet mineral resources, there are indications that the assessments of some deposits have been overly optimistic. Recently Soviet geologists have come under criticism by party leaders for poor quality geological prospecting, general mistakes, and inadequate confirmation of reserves leading to project changes, increased expenditures and other negative consequences.[26] According to Soviet reports many projects based on initially exaggerated discoveries have had to be dropped after expensive reinvestigations.[27]

In the Pechora Basin coal production is centralized in the Vorkuta district in Komi A.S.S.R., on the tundra at the northern foothills of the Ural Mountains. Vorkuta and several smaller places in the mining district are linked to Leningrad by a double track electrified railroad. The railroad has also been extended through the northern Urals to Labytnangi, north of the Arctic Circle and opposite Salekhard on the northwest shore of the Ob' River. Another spur northward now reaches the port of Kara on the Arctic coast of the Kara Sea. Production in the Pechora Basin reached 23 million tons of raw coal in 1973. However, coal production statistics are reported somewhat differently in the Soviet Union than in the West. Soviet coal production, though often reported to be larger than that of the United States, is actually smaller, when allowance is made for its low average heat content and for the fact that it is reported on a raw rather than a cleaned basis. Occasionally, the Russians report a figure for net output, or cleaned coal, but even that figure is inflated because some of the raw coal is cleaned by consumers such as the Ministry of Ferrous Metallurgy rather than the Ministry of the Coal Industry. Over half of all coal is shipped to consumers, mainly electric power stations without cleaning, and much of what is counted as clean coal (middlings, slurry, and screenings) contains a large amount of rock. Western practice is to report coal production in terms of clean or prepared coal.

The coal deposits around Noril'sk have been mined during the last 35 years not only for the supply of the city of Noril'sk (population 130,000) and the industrial plants there, but also for bunkering ships arriving on the Northern Sea Route at Dudinka, Ust'Port, and Dikson. The Noril'sk mining area is one of the world's greatest deposits of nickel and associated metals. Limited mining of coal at other Arctic locations, primarily Sanger, Arkagala, Zyryanka has been almost entirely for local use.

Other solid fuels, mainly oil shale, peat, and wood are used as substitutes for coal in the Soviet Union in thermal electric power plants, etc. In 1972 the Soviet Union produced 82.5 million tons of peat of which 61.2 million tons consisted of fuel peat.[28] Over 50 Soviet electric powerplants with a total capacity of about 3,000 megawatts are fueled by peat. The standard coal equivalent of the peat, oil shale, and fuelwood combined totals about 55 million metric tons annually, excluding fuelwood gathered by the general population which is estimated to amount to as much as 30 million tons of coal equivalent per year.[29] Approximately two-thirds of the 23 million tons of oil shale produced annually by the Soviet Union is used directly as fuel in thermal electric plants.

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[25] Strishkov, V. V., G. Markon and Z. E. Murphy. Soviet Coal Through 1980. Mining Congress Journal, October 1974, p. 42.

[26] Engineering and Mining Journal. August 1975, p. 143.

[27] U.S. Bureau of Mines, op. cit., p. 814.

[28] Ibid., p. 850.

SOVIET MINING TECHNOLOGY

Soviet production of raw coal has continued to increase in recent years. However, this increase has been achieved mainly through increased labor and capital rather than advancing technology. Comparative indicators of the U.S. and Soviet coal industries are given in Table 3.

TABLE 3.—COMPARATIVE INDICATORS FOR COAL INDUSTRY, 1972

	U.S.S.R.	United States	United States/ U.S.S.R.
ALL COAL MINING			
Output:			
Natural tons (metric) as reported (10^6)	655.2	[1] 537.9	0.82
Corrected to cleaned basis (10^6)	524.2	537.9	1.03
Heat content as reported standard tons (10^6)	459.8	[1] 522	1.14
Employment (number of employees, 10^3)	1,056	[2] 159.3	.15
Capital:			
Fixed assets	11.6 BR	[3] 4.758 B$	(4)
Underground equipment:[5]			
Continuous mining machines	4,107	1,849	.45
Coal cutting machines	359	1,890	5.26
Loading machines	4,518	1,959	.43
Conveyers	48,733	3,776	.08
Electric locos	13,000	3,412	.26
Rubber tired tractors	(6)	1,937	(4)
Shuttle cars	(6)	6,367	(4)
OPEN-PIT OPERATIONS ONLY			
Output: Natural tons (metric) as reported (10^6)	190.2	[7] 246.0	1.29
Employment (number of employees, 10^3)	[6] 72.8	[2] 17.7	.24
Capital:			
Fixed assets	[9] 1.23 B$	[3] 1,032 B$	(4)
Equipment:[5]			
Number of 1-bucket excavators	1,356	3,238	2.39
Average capacity of excavator shovels (m^3)	3	5-6	----------
Number of scrapers	(6)	360	----------
Number of front-end loaders	(6)	2,211	----------

Notes: U.S.S.R. data, from standard statistical handbooks, except as noted.

[1] "Statistical Abstract of the United States."
[2] "1972 Census of Mineral Industries."
[3] "1972 Census of Mineral Industries," value of mineral properties excluded.
[4] Not applicable.
[5] "Minerals Yearbook" and "Nar Khoz SSSR."
[6] Negligible.
[7] "Minerals Yearbook, 1972."
[6] Division of total rabochie between open pit and underground can be figured from avreage monthly output figures, and 1972 total employment is allocated in that proportion.
[9] Based on "Ugol'," 1974:11, p. 48.

Note: In 1972, 47.3 percent of coal was cleaned, and for the part cleaned in the Ministry of the Coal Industry, losses and rock were 15.7 percent. Another 27.5 percent was middlings, fines and screenings, with a large share of rock. Ash content of all coal shipped, including that which had been cleaned, was 20 percent. As an approximation, deduct 20 percent of total raw coal output as an allowance to clean it to U.S. levels.

Source: Campbell, R. W., "Technological Levels in the Soviet Energy Sector," "East-West Technological Cooperation, Colloquium-1976," NATO Directorage of Economic Affairs, Brussels, Mar. 17, 18, 19, 1976, 33 p.

According to the U.S. Bureau of Mines' analysis of Soviet reports, the technical standards and the quality of coal mining machinery and equipment are poor.[30] Equipment utilization is low; about 70 percent of the mining machinery and equipment is under repair or inoperative at any given time.[31] The low degree of utilization of machinery results from defects in construction, lack of sufficient repair shops and spare parts, poor work organization, and poor training of operators. Mining equipment is frequently operated 22 to 24 hours per day without scheduling servicing and preventive maintenance. Consequently, expensive equipment is rapidly worn out or becomes inoperative.

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[29] Central Intelligence Agency, Soviet Long-Range Energy Forecasts. Research Aid, September, 1975, p. 7.
[30] Ibid., p. 843.
[31] Ibid., p. 844.

The production of mining equipment has increased substantially in the Soviet Union but the equipment is standard and of the same types made earlier in Western Europe and America.[32] Machinery plants have been criticized in the Soviet press for the poor quality of their products. Frequently plants continue to turn out old models rather than to develop or even retool to reproduce new technology. Some Western observers have suggested that problems of this sort are the result of a quota oriented production system.

Soviet observers to American coal mines have been impressed by the organization of labor engaged in getting coal out without the extensive management that is characteristic of Soviet mines. Soviet observers have also commented on the high capacity, reliability, quality and design for specific situations of American mining equipment.[33] An American delegation visiting Soviet mines reported "It was our impression that the mines were overmanaged and overengineered, and yet in some respects were lacking in use of available and known technology." [34]

An indication of the lack of technological improvement through mechanization in Soviet coal mining is evident in the high use of manual labor compared to the West. Manual labor is used almost exclusively in longwall roof support (79,000 workers), loading of coal in longwalls (49,000), roof support in development workings (24,000), loading of coal and rock in development workings (20,000), and repair of workings (76,000 workers). Even in faces equipped with wide-web continuous miners and cutters, large amounts of coal are being extracted by blasting. The application of a prop-free face system and coal planers in Soviet longwall coal mining followed about 12 years after their introduction into the coal mines of Great Britain and West Germany. The first Soviet 65-ton truck, built in Byelorussia, was being tested in a coal mine in eastern Siberia in 1972 and 1973 but production has been continually delayed. Coal-cutting equipment for mining steeply dipping seems has been purchased from France and is being assembled in the Soviet Union.[35]

Coal preparation is not widely applied in the Soviet Union. According to Soviet sources, new coal preparation plants are equipped with low productive equipment. The plants are not supplied with adequate spare parts and are not fully mechanized. As a result, many workers are employed in the labor-intensive manual removal of rock. The U.S. Bureau of Mines, Minerals Yearbook 1972 states:

> Because Soviet coal preparation facilities are inadequate, the resultant losses in the fuel efficiency of the overall economy are staggering. Among the most prominent negative effects of inadequate coal preparation and classification are (1) inefficient combustion in the use of coal containing refuse; (2) high rail

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[32] Strishkov et. al., op. cit., 1974, p. 47.

[33] Campbell, R. W. Technological Levels in the Soviet Energy Sector. East-West Technological Co-operation. Colloquium—1976. NATO Directorate of Economic Affairs, Brussels, March 17, 18, 19, 1976, p. 7.

[34] Yancik, J. J. Some Impressions and Observations of Soviet Coal Mining. Mining Engineering, v. 26, July 1974, p. 65.

[35] Ibid.

transportation costs increased by moving inert wastes in coal; (3) additional supply burdens caused by the displacement of specific coals to accommodate transportation problems; and (4) aggravated existing shortages leading to still further diseconomies of resorting to more costly expedients, crosshauls of coals, and inadequate use and underuse of rail equipment.[36]

Soviet estimates of coal losses due to the use of unprepared coals at electric power plants in 1973 were placed at about 25 million tons in terms of raw coal. Loss by rail transportation of untreated coal amounted to 33 million tons of raw coal, or about five percent of the total output. Losses in transportation and transloading were reported at about 10 million tons of coal, and expenditures for cleaning coal spills from railroads at 50 million rubles.[37]

These losses add to existing shortages which increases the drive to stimulate production, leading to a spiral of still greater emphasis on quantity at the expense of quality. One estimate states that the Soviet economy experiences a 35 percent loss from inefficiency in the production, transportation, and use of unprepared coal.[38]

Another problem besetting coal beneficiation facilities in the Soviet Union is the size of the coal. Because of their low technical quality very few machines yield large lumps. The high proportion of fines in coals shipped to Soviet preparation plants (50 to 70 percent compared with 30 to 40 percent delivered to the plants of West European countries) greatly complicates the relatively low level of Soviet coal preparation technology, raises costs, and lowers the productivity of labor and plants.[39]

According to Soviet sources new preparation plants are frequently put into operation in spite of numerous imperfections and insufficient equipment. All 143 coal preparation plants of the U.S.S.R. Ministry of Coal Industry, on the average, are idle about 30 percent of the working time.

Mines and preparation plants alike have little concern about the quality or condition of coal they ship. In 1972, 384,000 tons of coal and in 1973 250,000 tons were sent back to the mines and dumped on waste piles. In wintertime, preparation plants sometimes dispatch wet coal, which freezes in transit into a solid mass and becomes impossible to unload.[40] During the period 1928–1973, the quality of marketable coal in the Soviet Union declined by 41 percent from an average of 6,940 kilocalories per kilogram in 1928 to about 4,900 kilocalories per kilogram in 1972. The officially reported ash content of coals shipped from Soviet mines increased to over 20 percent in 1973.

Labor productivity is a common theme in the Soviet press and given much emphasis in official statistical reports. Because of the differences in the way statistics are reported in the Soviet Union, direct comparisons with Western data tend to give a distorted and exaggerated picture of Soviet progress in coal production and technology. For example, in 1973 the average monthly production of the Soviet coal miner was officially reported as 69.7 tons. However, these data refer only to a limited group of "production workers" whereas in the West all wage earners are counted. Furthermore, Soviet production is based on unprepared or run-of-the-mine coal while it is the practice elsewhere to measure productivity in terms of marketable coal. In terms of Western criteria Soviet labor productivity is about one-third that of British and West German miners and about one-twelfth that of U.S. coal miners.[41]

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[36] U.S. Bureau of Mines, op. cit., p. 843.
[37] Pravda, Nov. 27, 1973.
[38] Strishkov et. al., op. cit., 1974, p. 50.
[39] Ibid., p. 49.
[40] Pravda, Jan. 28, 1974.

The Soviet Union does not publish statistics on injuries in the coal industry. However, available Soviet information indicates that fatal injuries in the coal industry are high. In 1970 fatal injuries occurred at 45 percent of the Soviet coal mines.[42] Furthermore, production and development faces were very dusty leading to hazardous and unhealthy working conditions.

The current five year plan, 1971–1975, places strong emphasis on the development of coal deposits of Siberia and Kazakhstan by surface mining. According to some analysts, the Soviet move to develop new coal regions in the East is not because the deposits nearer European Russia, particularly the Donets Basin, are becoming exhausted, but that the labor supply and labor productivity are too low to supply the coal necessary for Soviet industrial expansion. Russian underground mining technology has not been able to adequately increase productivity. In 1913 the per shift production of commodity coal in the Donets Basin was 0.61 ton. By 1973 this was increased to 0.95 ton, an increase of only 0.34 ton, despite the immense technical progress that has taken place elsewhere in the world during the same period. Siberian coal can be strip mined at a higher rate of productivity, but massive shipments to European U.S.S.R. will require the construction of additional transportation systems.[43] The Trans-Siberian railroad is already congested and the northern coal regions are not even reached by rail. A more northerly Trans-Siberian railway, the Baikal-Amur Magistral or BAM, running north of Lake Baikal is under construction and scheduled to open in 1983 but harsh climate and terrain are creating construction problems.[44] According to some observers savings from cheaper strip mining of Siberian coals are exceeded several times over by the increased shipping costs, but within a controlled economy costs are disseminated throughout the entire system. However, a strong incentive to develop some of the more inaccessible Siberian coal deposits is the need for high quality coking coal used in the steel industry as reserves of coking coal in European Russia are dwindling.

Development of mining projects in the Soviet Union takes much longer than in the West. Frequently instead of 5 or 6 years as planned, 10 to 12 years elapse before a given enterprise comes into full production. To expedite development of its energy resources, the Soviet Union is attempting to secure trade agreements for foreign technology and assistance. On April 30, 1974 an agreement was signed with Japan for assistance in developing the Neryungra coalfield in the southern region of Yakutia. Japan is to provide the Soviets with $450 million worth of mining and railway equipment between 1975 and 1981. Exports of coal from this field to Japan are planned to begin in 1983 at the level of 3.2 million tons per year, increasing to 5.5 million tons in 1985, and continuing through 1998. A deepwater port for coal transhipment is being constructed at Wrangel Port with the aid of Japanese engineers.

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[41] Strishkov et. al., op. cit., 1974, p. 48.
[42] Ibid., p. 52.
[43] Slocum, M. Soviet Energy: An Internal Assessment. Technology Review, Oct./Nov. 1974, p. 16–33.
[44] Adzhiev, M. E. Taming the Siberian Taiga. New Scientist, February 19, 1976. p. 382–384.

Another coal technology trade agreement was recently announced involving Kaiser Industries' Canadian subsidiary Kaiser Resources Ltd., Mitsui Mining of Japan, and the Soviet Union.[45] The agreement would transfer strip-mining technology from Canada to the eastern Siberian coal fields in exchange for license rights for Soviet hydraulic coal mining technology. Under the agreement both Kaiser and Mitsui would pay $200,000 for technology license rights and up to $600,000 from licensing royalties they may make with other Western companies. In addition they will share with the Soviets royalties from the manufacture and sale of hydraulic mining equipment. The Soviet Coal Ministry claims to have 1700 experts engaged in hydraulic mining research and development.

FUTURE PROSPECTS FOR COAL FROM ARCTIC RUSSIA

The Soviet Arctic is a rich storehouse of coal resources if it can be effectively exploited. However, the vast majority of the resources are located in inhospitable, inaccessible areas, far from major consuming centers. Development of these coal resources will involve a considerable effort and divert funds and materials from development of other energy resources. A major incentive for development of some Siberian coal deposits will be to obtain high quality coal for coking. Less expensive mining methods may be overshadowed by higher transportation costs.

The future development of coal resources in the Soviet Arctic is complicated by a number of factors including: the harsh environment, difficulty of construction, massive capital requirements, and development of an adequate transportation system over immense distances. Siberia's major rivers flow northward against the direction of coal transport, and are closed to winter navigation. New construction techniques will need to be developed to combat the severe icy conditions and low wintertime temperatures, swampy summertime conditions, ground movement, and high winds frequently experienced in some areas. Development in the Soviet Arctic is currently hampered by the lack of proper technology, equipment suitable for Arctic and subarctic operations, and proper repair facilities.[46] Labor shortages and high turnover rates aggrevated by substandard living conditions, acclimatization difficulties, high cost of living, and the scarcity of consumer goods have contributed to the problems of developing the Soviet Arctic. Recent agreements with Comecon countries on the development of Siberian resources include provisions for the supply of labor from Comecon countries.

SOVIET COAL GASIFICATION

Experiments on in situ coal gasification began in the U.S.S.R. in 1933 and have been carried out at eight sites on a variety of coals ranging from lignite to bituminous. Since 1946 experimentation and development has been greatly intensified, and by 1960 the process apparently reached the threshhold of commercial application. Despite large discoveries of oil and gas, Soviet interest in coal gasification remains strong. A recent Soviet proposal suggests that the Pechora coal be hydrogenated and gasified and that the synthetic fuel thus obtained be exported to Western Europe through northern Soviet ports.[47] The paper also broached the possibility of processing coal in the same manner from the Tungas, Taymyr, and Lena Basins which contain tremendous estimated resources of hard and brown coal.

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[45] Coal Age, December 1974, p. 39–40.
[46] Slocum, op. cit., p. 30.

Three plants are now in operation in the Soviet Union with two of them classified as commercial operations producing low-BTU gas.[48] The two commercial-scale plants have been in operation for more than 10 years, one in Angren, Uzbekistan, and the other in Yuzhno-Abinsk, western Siberia. Each supplies a nearby power plant with fuel gas with a heating value of 85–100 BTU. A third plant at Tula, near Moscow is used for research and development.

The Russian gasification process has been successful with coal deposits from 45 to 300 meters (150 to 1,000 feet) in depth and with seam thickness from 1.5 to 20 meters. Conventional rotary drilling techniques are used to penetrate the coal beds. Air is injected through some holes to maintain the underground combustion and the product gas withdrawn through other holes.

The Russians have found that about 70 to 80 percent of the coal in place is burned and about 60 percent of the energy in the burned coal is recovered as usable above ground energy. Because of the low BTU content of the gas, it is not economically practical to transport it more than about 16 kilometers.

The U.S. license for Russian gasification techniques has been assigned to Texas Utilities Services Inc., Dallas, which plans a demonstration plant on lignite deposits near Fairfield, Texas.[49] With large coal resources, a breakthrough in coal gasification technology would be of significant benefit to both the United States and the Soviet Union.

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[47] Central Intelligence Agency. Soviet Long-Range Energy Forecasts. Research Aid, September 1975, p. 22.

[48] The Oil and Gas Journal. August 4, 1975, p. 38.

[49] Ibid.

OIL AND NATURAL GAS

Alaska

INTRODUCTION

Alaska is located at the northern end of the American Cordillera which is a continuous mountain system that extends along the entire length of western North and South America. Thus, Alaska is similar in geologic structure and physiography to the other parts of this long system of mountains. Dynamic earth processes continually alter Alaska. The Gulf of Alaska-Aleutian chain area is one of the most earthquake prone areas of the world. Further north, permafrost (permanently frozen ground) also becomes an operational problem. The areal distribution of permafrost is quite variable, ranging from isolated patches to broad deep areas. Most of the existing permafrost formed during the Pleistocene ice age and relict thickness exceeding 30 meters are common, while a maximum thickness of 600 meters has been encountered in the Prudhoe Bay region. Alaska contains widespread Paleozoic and Mesozoic sedimentary rocks, while Tertiary sediments are limited in extent and generally restricted to the southern and northern coastal areas and also to a few elongate sections of the interior.

The discovery of the Prudhoe Bay oil field by the Atlantic Richfield Company in 1968 opened a new phase of petroleum exploration and development in Alaska. There is now no doubt that the petroleum potential of Alaska is great as is the size of the reserves at Prudhoe Bay, the potential resource there being in keeping with the size and favorable setting of this Arctic sedimentary province.[1]

Alaska may be divided into the following petroleum provinces (see Figure 8):[2] Alaska Peninsula-Cook Inlet Province; Nushagak Lowland and Bristol Bay Tertiary Province; Bering Sea Shelf Province; Pacific-margin Tertiary Province; Yukon-Koyukuk Province; Arctic Slope Province; and Yukon-Porcupine Province.

ALASKA PENINSULA—COOK INLET PROVINCE

The Alaska Peninsula-Cook Inlet Province extends from the Chitina Valley southwestward across Cook Inlet to the end of the Alaska Peninsula. It is a lowland which is bounded on the north and west by the Alaska Range and on the south by the Keni-Chugach Mountains.

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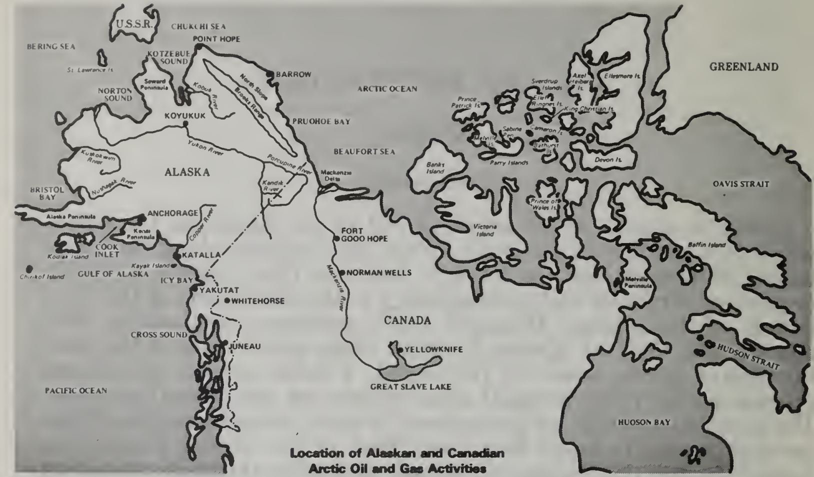
[1] Grye, George. Summary of Potential Petroleum Resources of Region 1 (Alaska and Hawaii)—Alaska. Future Petroleum Provinces of the United States—Their Geology and Potential, Memoir 15, The American Association of Petroleum Geologists, Tulsa, Oklahoma, 1971, p. 55.

[2] Ibid. p. 59–67.

FIGURE 8



Location of Alaskan and Canadian Arctic Oil and Gas Activities

Commercial accumulation of oil and gas in the province are in nonmarine Tertiary rocks and these Tertiary rocks, and possibly Upper Mesozoic rocks, are also believed to have the best possibilities for future discoveries.[3]

In 1853 oil seeps were observed on the western shore of Cook Inlet, but it was not until 1957 that oil in commercial quantities was discovered in the area. This first discovery was at Swanson River on the Kenai Peninsula and was made by the Richfield Oil Company. Since that time six oil fields have been discovered and developed in the area about 18 gas fields have been found.

It has been estimated that the discovered oil in-place amounts to about 2.6 billion barrels and that the discovered in-place gas is about five trillion cubic feet.[4] It has also been estimated that ultimately a total of 7.9 billion barrels of oil and 14.6 trillion cubic feet of natural gas may be discovered provided that new reserves are discovered in shallower and/or deeper zones of existing fields, that field limits are extended and new pools are discovered near existing fields, that new accumulations are discovered in stratigraphic traps, that areas now closed for leasing are drilled, and that frontier areas such as the Susitna Basin the Mesozoic rocks which underlie Cook Inlet are explored.

Other fields in the province include the Kenai West Fork, the Falls Creek, and the Sterling gas fields, discovered in 1959, 1960, and 1961 respectively. The West Foreland and Beluga gas fields were located in 1962 near the Cook Inlet. Offshore drilling began in Cook Inlet in 1962 with the discovery of the North Cook Inlet gas field and the Middle Ground Shoal oil gas field.[5] Development drilling in Cook Inlet followed rapidly and there are now 15 offshore platforms which produce oil and gas from the fields in the inlet.[6] Other offshore fields include Granite Point, McArthur River, and Trading Bay. The crude oil is carried by a network of pipelines from the platforms to the Drift River tanker terminal on the west side of the inlet or to the Nikiski terminal north of Kenai. In recent years, the Cook Inlet-Swanson River fields have produced about 60 million barrels of oil and 230 billion cubic feet gas per year.

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[3] Ibid. p. 59.
[4] Ibid.
[5] Mueller. Ernst, Alaskan Oil—The Energy Crisis and the Environment. Arctic Bulletin, v. 1, n. 5., 1975, p. 186.

Cook Inlet is an elongate, northwest trending coastal embayment in south central Alaska, east of the Alaska Peninsula. The inlet is about 137 kilometers long with a water depth averaging less than 90 meters, but the depth increases southward to over 180 meters at the mouth of the estuary. Bottom sediments are fine-grained silts and clays from rivers which drain the rugged, glacial terrain which surrounds the inlet. Cook inlet is both a topographic and a structural basin that contains about 18,000 meters of Mesozoic and Cenozoic sediments. The older Mesozoic strata, which crop out around the edge of the basin, are mostly of marine origin, while the thick younger Tertiary rock sequence is largely non-marine. The basin is bounded by faults which parallel the northerly structural grain of the region. The structural ridges within the basin are aligned in a similar manner, and many of these anticlines are associated with long parallel reverse faults. All of the oil and some of the gas discovered in the upper Cook Inlet fields have been in structural traps along these trends. The Supreme Court has cleared the way for the Federal Government to lease lower Cook Inlet. By a six-to-two vote, the high court reversed two lower court decisions and ruled that the Federal Government and not the State of Alaska owns the leasing rights to the land beneath the lower inlet. The offshore wells in upper Cook Inlet are on State lands.

The Department of the Interior has selected 152 tracts totaling 865,364 acres for a Fall oil and gas lease sale in lower Cook Inlet. The original areas covered 450 tracts totaling 2.3 million acres and sixteen companies nominated 433 tracts totaling 2.1 million acres.[7] The tracts are in an area about 50 kilometers wide and 130 kilometers long in waters from about 30 to 170 meters deep. Industry response was heavy even though the area has not been explored in detail. This is because upper Cook Inlet has been drilled and its potential is known.[8]

About one-third of the Cook Inlet area (upper Cook Inlet) has been explored by drilling, while lower Cook Inlet is essentially unexplored. Available data indicate that the lower inlet has a thinner stratigraphic section and also less structural potential than the upper inlet. However, promising structures are present and the erratic distribution of non-marine Tertiary strata within the sedimentary sequence suggests that stratigraphic traps could also occur throughout the basin.[9]

Lower Cook Inlet lies within the seismically active zone of southern Alaska and at least 12 major earthquakes (magnitude greater than

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[6] Ibid.

[7] Interior Picks 152 Tracts for Fall Lower Cook Inlet Lease Sale. The Oil and Gas Journal, March 8, 1976, p. 29.

[8] Ibid.

[9] Final Environmental Statement. Proposed Increase in Oil and Gas Leasing on the Outer Continental Shelf. U.S. Department of the Interior, Bureau of Land Management, Volume 1, July 7, 1975, p. 351.

Richter scale six) have occurred in the area since 1899. Although the eastern half of Cook Inlet is located within the area of major tectonic deformation associated with the 1964 Prince William Sound earthquake, the existing oil and gas wells were not appreciably disturbed. Fissured ground, mud and landslides, and intense ground movements were widespread, however, and could pose potential hazards to future oil and gas development during periods of seismic activity. Augustine Island, an active volcano located in southwestern Cook Inlet, represents a potential volcanic hazard to future oil and gas operations in the lower inlet. Of the five volcanoes that are present in the vicinity of western Cook Inlet, three have erupted during the past 21 years, causing local damage from ash falls, sea waves, and flooding.

The U.S. Geological Survey places the undiscovered hydrocarbon resources in lower Cook Inlet at 0.5 to 2.4 billion barrels of oil and 1.0 to 4.5 trillion cubic feet of natural gas. The lower amount is that judged to be discoverable and recoverable at a 95 percent level of confidence and the higher amount is that judged recoverable at a five percent level of confidence.

Of the discovered oil fields in the Alaska Peninsula-Cook Inlet Province, three rank in the top 100 fields in the United States. These are as follows: the McArthur River field of the Kenai Peninsula (reserves of 249,660,000 barrels of oil with a 113,000 barrels of oil per day capacity in 90 days); Middle Ground Shoal, Kenai Peninsula. Cook Inlet (reserves of 97,836,000 barrels of oil with a 24,000 barrels of oil per day productive capacity in 90 days); and Swanson River. Kenai Peninsula (reserves of 68,878,000 barrels of oil with a 26,000 barrels of oil per day productive capacity in 90 days).

The southern Aleutian Shelf forms a narrow arcuate zone that occurs between the Aleutian Islands-Alaskan Peninsula on the north and the Aleutian Trench on the south. The width of the shelf varies from less than 80 kilometers west of Unimak Island to about 240 kilometers near Kodiak Island in the east. The main shelf area is characterized by the presence of broad plains dissected by relict glacial drainage channels. The regional slope is generally less than 0 degrees 5 minutes. The shelf break is very distinct and occurs in waters from 120 to 130 meters deep off Unimak Island and in 150 to 160 meters deep waters off Kodiak Island. Beyond the continental shelf the steep, rugged continental slope drops more than 5,000 meters to the Aleutian trench over a horizontal distance of 30 to 80 kilometers. The tertiary rocks of the Kodiak petroleum region extend westward beneath the south Aleutian Shelf to the vicinity of Chirikof Island. Seismic data covering the western shelf is available, but insufficient lithological information exists to allow a full evaluation of the resource potential. Both seismic and volcanic risk is considered high in the area.[10] Tentative plans called for a lease sale in the Gulf of Alaska-Aleutian Shelf Area in October 1978.

Oil and gas seeps are known in the Middle and Upper Jurassic rocks of the Alaska Peninsula. Shows of oil have been reported in test wells in large, broad anticlines. No major hydrocarbon finds have been made in this region as yet, but some geologists believe that there are prospects for large and prolific fields in areas where Mesozoic rocks are overlain by Tertiary rocks containing good reservoir sandstone.[11]

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[10] Ibid.

In the Copper River-Chitina Valley region, an area of about 9,065 square kilometer there is a marine sedimentary sequence of Late Mesozoic age. Although the composite thickness of the sedimentary rocks in the region is about 7,620 meters, the average thickness is probably not more than half that. This sedimentary sequence is correlative with the petroliferous rocks in Cook Inlet and on the Alaska Peninsula.[12]

The region includes a possible source of petroleum in the predominantly marine Mesozoic sedimentary rocks and possible reservoir beds in the same rocks and also in Tertiary rocks that may underlie a thick surficial cover in the eastern half of the region. Local evidence of petroleum includes fetid odors in a few beds of Cretaceous age, gas shows in one or two test holes in Mesozoic rocks, and several seeps of high-methane and nitrogeneous natural gases.

The Copper River region does not appear to be as promising for commercial hydrocarbon production as either the Alaska Peninsula or Cook Inlet.[13] The State of Alaska, however, in 1974 estimated that 0.2 billion barrels of oil and 1.2 trillion cubic feet of gas are recoverable from The Copper River region.

THE NUSHAGAK LOWLAND AND BRISTOL BAY TERTIARY PROVINCE

The Nushagak Lowland-Bristol Bay Tertiary Province rocks are known mainly from a few reconnaissance surveys of scattered exposures along the margins of Bristol Bay and the Nushagak lowland. The petroleum potential of the region lies in a fairly thick sequence of interbedded marine and coal-bearing non-marine Tertiary age rocks which are likely to contain porous and permeable beds which could serve as petroleum reservoirs.[14]

The Bristol Bay Tertiary region is bounded on the south by the Aleutian Range and on the northeast by the Ahklun Mountains. It extends offshore into the Bering Sea to the continental slope in the vicinity of the Pribilof Islands.

The large Bristol Bay basin is a structural and sedimentary trough bounded by the Alaska Peninsula arch and the related Bruin Bay fault on the southeast and by the Goodnews arch and its seaward projection on the northwest. Exposures of highly-deformed locally introduced Palezoic and Mesozoic rocks mark the northeastern margin of the basin and its southeastern extension terminates with the continental slope. The northeast region of the Bristol Bay basin contains from 610 to 4,880 meters of non-marine and shallow water marine Tertiary rocks while the central portion is characterized stratigraphically by a thin non-marine sequence that thickens southwestward to over 3,660 meters, while becoming more marine in character. Structural deformation in the sedimentary sequence of the Bristol Bay basin is most pronounced along the western flank of the Alaska Peninsula arch, but extensive faulting has also occurred in the volcanic basement of the central section. These features, however, do not appear to extend into the overlying beds. The Mesozoic strata to the southwest have been faulted and broadly folded out to the edge of the continental slope while the overlying Tertiary section is only mildly deformed. Large commercial quantities of oil and gas may be anticipated in structural and stratigraphic traps in the wide belt of transition between the marine Tertiary section in the southwest part of the basin and the non-marine Tertiary section in the northeast. Other hydrocarbon accumulations are expected in the marine Mesozoic rocks of the southwest. An estimated two million acres of the Bristol Bay shelf may have petroleum potential.[15]

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[11] Gryc, George, op. cit., p. 60.
[12] Ibid.
[13] Ibid.
[14] Ibid.

Nine test holes, containing minor oil shows, have been drilled onshore, but none offshore. The best possibilities for large petroleum accumulations are likely to be located offshore.[16]

Estimates have been made that as much as one to five billion barrels of oil (or gas equivalents) may be recovered from the region.[17]

A lease sale is projected for the outer Bristol Basin in December 1977. The potential geologic hazards in the region primarily involve seismicity and permafrost. Sporadic volcanic activity along the southern coastal areas may exert a local influence.

BERING SEA SHELF PROVINCE

Nearly half of the Bering Sea is underlain by a relatively smooth continental shelf which forms the southern part of the large Bering-Chukchi platform. The Bering shelf section in some areas extends offshore over 645 kilometers. Water depths over the Alaskan Bering Sea shelf average around 55 meters. The shelf is virtually flat, but terminates abruptly seward at about 160 meter water depth to one of the steepest known continental slopes. The irregular slope drops at average declivities often exceeding 20 degrees from the shelf break to the 3,800 to 3,900 meter deep Bering Sea basin. There are several islands in the Bering Sea. These are usually composed of thick accumulations of volcanic flows and debris interbedded with sedimentary strata.

Acoustic reflections indicate the presence of a generally thin cover of Holocene sediments overlying the Southeastern Bering Sea shelf. Holocene sediments vary in thickness from zero to ten meters, and average about three meters. The unconsolidated Holocene sediment cover over the northeastern Bering Sea shelf is also thin, but is more variable in thickness. The predominant sediment type in the area is fine sand in contrast to the even finer-grained bottom sediments in the Chukchi Sea to the north. Most of the Holocene sedimentation along the eastern Bering shelf appears to have been deposited at delta fronts of the major coastal rivers. There has been relatively little redistribution of this material across the shelf.

There are several sedimentary and structural basins on the continental shelf of the Bering Sea which contain Cenozoic sediments. The Norton Basin, covering an area of about 100,000 square kilometers, extends from the shores of Norton Sound westward to Cape Chukotsky and between the Seward Peninsula on the north and St. Lawrence Island on the south. This basin contains up to 2,000 meters of marine and non-marine Cenozoic strata that is similar to the Bristol Bay basin sedimentary sequence to the southeast. The Pribilof, St. George, Zhemchum, Navarin, and other similar but unnamed basins are elongate outer-shelf basins of broadly deformed and faulted marine deposits which parallel the northwestern trend of the margin of the shelf. The inner-shelf Norton and Bering Sea basins represent large structural sags. Many of the outer-shelf basins appear to be controlled by faults.[18]

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[15] Final Environmental Statement, Proposed Increase in Oil and Gas Leasing on the Outer Continental Shelf, op. cit., p. 357.

[16] Gryc, George. op. cit., p. 60.

[17] Ibid.

Petroleum prospects on the outer continental shelf of the Bering Sea include: the basins containing thick sections of Cenezoic and, in some areas, Cretaceous sediments; the deformed Mesozoic sedimentary rocks which underlie many of these basins; the dome and diapiric structures associated with the more deeply submerged (2,000 meters) Umnak plateau area; and, the thick masses of Late Tertiary beds in summit basins along the crest of the Aleutian ridge.[19]

Among the most promising prospects appear to be the thick accumulations of Early Tertiary through Holocene sedimentary strata that occur in the larger inner-shelf basins which underlie the shelf's major bays and gulfs, such as the Norton Basin. Many outer-shelf basins are underlain by folded Cretaceous and Jurassic strata which may be prospective in themselves and also may have supplied hydrocarbons to the overlying Cenozoic structures. Other promising areas are the rather large (some as much as 30 by 80 kilometers) summit basins of the 2,200 kilometer long Aleutian Ridge. These basins are roughly rectangular in shape and elongated parallel to the ridge. The floors of two of them, the Amukta and the Amlia basins, lie in water about 1,000 meters deep and are underlain by a three to four kilometer thick Late Tertiary sedimentary sequence. These basins are bordered by major normal faults and are also disrupted by high-angle growth faults.[20] The State of Alaska estimated in 1974 that 27.4 billion barrels of oil and 200 trillion cubic feet of gas are potentially recoverable from the Being Sea shelf.

A Federal lease sale has been tentatively scheduled in March of 1977 for the St. George Basin, a Bering Sea shelf basin which extends from St. George Island in the Pribilofs about 360 kilometers to Unimak Island in the Aleutian Chain off Bristol Bay. A second Federal lease sale has been tentatively set for the Norton Basin in August, 1978. The Department of the Interior has called for tract nominations in a more than 4,160 square kilometer area for the St. George Basin sale.[21]

PACIFIC-MARGIN TERTIARY PROVINCE

In the southern coast area of Alaska, the Alaskan Pacific-margin Tertiary basin is a 1,450 kilometers long structural feature that is roughly parallel to the southern coast of Alaska between Cross Sound and Chirkof Island. The basin covers an area of about 103,600 square kilometers and lies mostly offshore. It is underlain by a thick sequence of Tertiary continental and marine strata varying in age from Paleocene through Pliocene. The basin sequence includes a lower unit of well-indurated intensely-deformed Early Tertiary rocks overlain by a less-altered section of Mid to Late Tertiary strata. The Middle to Late Tertiary rocks appears to have the best reservoir potential. Where exposed, the Early Tertiary age rocks are hard and tightly cemented and appear to have little reservoir potential. The average thickness of Middle and Late Tertiary rocks is 3,050 to 4,570 meters and their volume in the basin has been calculated to be from 129,500 to 194,250 cubic kilometers.[22]

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[18] Final Environmental Statement, Proposed Increase in Oil and Gas Leasing on the Outer Continental Shelf, op. cit., p. 358–360.
[19] Ibid., p. 360–361.
[20] Ibid.
[21] Alaska. Offshore, June 20, 1975, p. 117.

The Tertiary basin is subdivided into two petroleum regions, the Gulf of Alaska Tertiary region to the east and the Kodiak Tertiary region to the west. Although tratigraphically similar, the two regions display significantly different structural trends. The geologic structure of the Gulf of Alaska is characterized by east-west tending features including fault types similar to those found onshore. The Kodiak region contains geologic structures which trend at a 45 degree angle to those in the Gulf of Alaska and also contains a nearshore zone of high angle faulting of the Aleutian structural system.[23] A Federal lease sale is planned for December 1976, featuring offshore tracts east of Kodiak Island.

Since 1954, oil companies have drilled 26 dry holes along the narrow shoreline between the mountains and the Gulf of Alaska. At least a dozen of these tests were drilled as deep as 3,050 meters and one went to 4,480 meters.[24] There has been one small success in the area, the shallow Katalla oilfield, discovered onshore near Kayak Island in 1902. The field, now abandoned, produced a total of 154,000 barrels of oil from 22 wells which ranged in depth from 110 meters to 545 meters. The Katalla field does prove that there are hydrocarbons present in the region. Onshore drilling locations are limited because of the Chugach Mountains and the subsurface geology is complex. However, recent seismic surveys run along the continental shelf offshore from Katalla and in other sections of the Gulf of Alaska indicate the presence of well defined structures. In the Icy Bay area there are apparently two large structures which parallel each other and trend roughly east to west, with the structure lying to the south being the largest.[25]

Between Icy Bay and Kayak Island the Gulf of Alaska shelf appears to contain two basic types of geologic structures. The first is a series of asymmetric linear folds that trend northeast to southwest across the shelf. The second is a large, gently dipping arch between Kayak Island and the Bering trough which parallels the coast. Between the arch and the coast is a broad downwarp (as much as 95 kilometers in width) within which there may be some local upwarping. To the west of this area, between Kayak and Middleton Island, there is a broad zone of complex structures which trend northeast-southwest. In general, the structural highs tend to be asymmetric and bounded by faults on their southeast limbs.[26]

In the Gulf of Alaska region, the problem of the noncommercial oil found onshore concerns the lack of sufficient porosity and permeability in the reservoir sands. The unknown regarding the offshore potential is whether the Tertiary rocks which outcrop onshore have producible oil in them offshore. The Tertiary rocks dip away from the shore and thus drilling, in general, will have to be deeper as the distance from shore becomes greater. Four formations within the Tertiary will be carefully tested. The youngest is the Yakataga, of Middle Miocene to Lower Pleistocene age. Next is the Katalla, Lower and Middle Miocene, underlain by the Poul Creek, age Middle and Upper Oligocene. The oldest formation of special interest is the Kultieth, a 810 meter thick sequence of Middle and Upper Eocene and Oligocene.[27] In addition some of the even younger formations may have hydrocarbon potential, especially in areas farther from shore.

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[22] Gryc, George, op. cit., p. 61.

[23] Final Environmental Statement, Proposed Increase in Oil and Gas Leasing on the Outer Continental Shelf, op. cit., p. 347.

[24] Wilson, Howard M. Big Plans on Tap for Two Alaskan Wildcat Areas. The Oil and Gas Journal, June 2, 1975, p. 106.

[25] Wilson, Howard M. Where is Icy Bay? The Oil and Gas Journal, April 26, 1976.

[26] Wilson, Howard M. Big Plans on Tap for Two Alaskan Wildcat Areas. op. cit., p. 109.

The first Federal oil and gas lease sale in the Gulf of Alaska was held on April 13, 1976. The sale (number 39) brought a total of 244 bids on 81 of the 189 tracts being offered. High bids totaled $571.9 million and total industry bids amounted to $1.7 billion. The highest bid ($62.76 million by the Texaco Group) was for a tract thought to lie on the south Icy Bay structure. A tract on the north Icy Bay structure received a bid of $41.1 million by ARCO and Shell. The Department of the Interior accepted high bonus bids in the sale totaling $599.8 million on 76 tracts, totaling 437,253 acres. The 189 tracts offered for sale totaled approximately one million acres. Interior rejected the high bids on five of the tracts because of the insufficiency of the bid. The highest bid from a consortium of Texaco, Allied Chemical, Diamond Shamrock, and Champlin Petroleum of $62,756,352 for tract 78 amounted to $11,023 per acre.[28]

The Bureau of Land Management estimates that about a dozen oil and/or gas fields are likely to be discovered in the northern Gulf of Alaska with an average distance from shore of about 35 kilometers. At assumed peak production, 22 platforms and a total of 800 producing wells are projected with 12 to 24 major pipelines, three offshore loading and storage terminals, and one liquid natural gas plant. According to the Bureau estimate, it will cost the petroleum industry $5.645 billion to develop the area.[29]

Shell Oil Company estimates that exploratory drilling in the Gulf in 150 meters of water will cost about $5 million for a 2,400 meter well and about $8 million for a 3,600 meter well. Shell feels that the production platforms will be of the steel-bottom-support type and will be specifically tailored to be able to withstand severe earthquakes. To accomplish this, the platforms will have to be designed so that the legs at the sea floor are dampened from strong ground motions.[30]

The semisubmersible rigs which will be used for most of the exploratory drilling, plus other support services, will cost an estimated $100,000 per day.

The U.S. Geological Survey estimates the undiscovered resources in the northern Gulf of Alaska to be 0.1 to 2.8 billion barrels of oil and 300 billion to 9 trillion cubic feet of gas. The lower estimate is considered recoverable at a 95 percent level of confidence and the higher amounts at a five percent level of confidence.[31]

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[27] Wilson. Howard M. Industry Near Long-sought Crack at Gulf of Alaska. The Oil and Gas Journal, March 15, 1976, p. 56–57.

[28] Interior Department Accepted High Bonus Bids Totaling $559.8 million in Sale No. 39. Coastal Zone Management. April 28, 1976, p. 5.

[29] Alaska Gulf Sale May Be Two Years Away. The Oil and Gas Journal, July 7, 1975, p. 28.

[30] Shell's Nanz Sees Alaska Development Costly. The Oil Daily, May 3, 1976, p. 6.

[31] Alaska Gulf Sale May Be Two Years Away. op. cit., p. 28.

Of particular environmental concern in this region is the problem of earthquakes, since numerous earthquakes of significant magnitude have occurred since 1899. The sale area is classified as extremely susceptible to earthquakes of 6 to 8.8 (on the Richter scale) magnitude with very intense quakes likely to occur once in every 20 to 25 years.

YUKON-KOYUKUK PROVINCE

The Yukon-Koyukuk province has been defined as an area underlain by Mesozoic rocks of about 259,000 square kilometers extending south from the Kobuk River to the Yukon River in the area of Koyukuk and Nulato and then continuing farther to the southwest to the coastal lowland. In 1960 to 1961 two deep wells were drilled in the region, a 3,658 meter test near Nulato and a 4,572 meter test at Napatuk Creek in the Yukon-Kuskokwim coastal lowland. The wells were apparently dry.[32]

From 1954 to 1968, the U.S. Geological Survey mapped the province on a reconnaissance scale and a few reconnaissance areomagnetic profiles have also been made. The rocks of the province are predominantly Cretaceous in age. Their structure is exceedingly complex. The general structural complexity of the rocks and the scarcity of favorable reservoir and source beds appear to limit the hydrocarbon potential to areas underlain by Cretaceous rocks of shallow marine and nonmarine origin. It has been suggested that the possible target areas may be limited to a belt about 32 by 483 kilometers extending from the western edge of the Koyukuk Flats southward to the Yukon-Kuskokwim lowland and a smaller area of 32 by 129 kilometers on the middle Kobuk River. Thus, the favorable areas would be confined to about 20 720 square kilometers and contain an estimated total volume of about 54,170 cubic kilometers of shallow marine and nonmarine sediments.[33]

Limited aeromagnetic data suggest that, in general, the lowland areas of this province are probably not favorable hydrocarbon exploration targets, with the possible exception of the Kobuk-Selawik lowland where the Kobuk coastal delta area and Kotzebue Sound may be underlain by Cretaceous and/or Tertiary sediments.[34]

The State of Alaska estimated in 1974 that the province contains 5.4 billion barrels of recoverable oil and 17.8 trillion cubic feet of recoverable gas.[35]

ARCTIC SLOPE PROVINCE

The Arctic Slope, also called the North Slope includes an area of more than 259,000 square kilometers of which at least 181,000 square kilometers is considered to have petroleum potential.[36]

The average thickness of sedimentary rocks in the province is about five kilometers and their total volume is about 875,100 cubic kilometers.[37]

Oil seeps along the Arctic coast have been reported since the early 1900's. In 1923, President Harding set aside 37,000 square miles (95,-

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[32] Gryc, George. op. cit., p. 62.
[33] Ibid.
[34] Ibid.
[35] Alaska Natural Gas Transportation System. Hearing before the Subcommittee on Public Lands, House Committee on Interior and Insular Affairs, Ninety-fourth Congress, First Session, U.S. Government Printing Office, Washington D.C., October 9, 1976, p. 55.
[36] Gryc, George. op. cit., p. 62.
[37] Ibid.

830 square kilometers) of the North Slope as Naval Petroleum Reserve No. 4 which has subsequently been explored for hydrocarbon deposits.

The continental shelf of the U.S. portions of the Beaufort and Chukchi Seas extend from the Alaska-Canada boundary westward to the international date line. The Chukchi Sea is located off the Alaskan Arctic coast and extends northward between Wrangel Island and Point Barrow to the edge of the continental shelf. The underlying Bering-Chukchi platform joins the North American and Asian continents. Water depths over most of the shelf are generally less than 55 meters and 40 meter depths commonly occur as far as 50 to 100 kilometers off the coast. The Chukchi continental shelf is generally smooth with minor irregularities on its outer margin. A broad topographic high shoals at 13 meters to the north of the Bering Strait.

To the west, a submarine canyon extends northward to the edge of the continental margin. Beyond the shelf, the continental slope descends from 65 meters to depths of about 180 meters. The continental rise is about 160 kilometers in width. The activity of ice has resulted in an irregular distribution of sediment types on the Chukchi continental shelf. Most of the shelf is venerred with a coat of unconsolidated gravel, sand, and mud derived from the mixing of poorly-sorted ice-rafted debris with normal shelf sediments.

A subsurface structural ridge, the Barrow arch, extends northwest from Point Barrow and then southwest across the northern Chukchi Sea, dividing it into two distinct terrains. A southward-thickening Mississippian to Jurassic sedimentary section extends between the Barrow arch and the northern foothills of the Brooks Range and its offshore extension. These older rocks are overlain by organic-rich Lower Cretaceous shales that are thought to have been the source of the oil trapped in the giant Prudhoe Bay field. Above these shales, younger Cretaceous rocks contain a major resource of sub-bituminous and bituminous coals and some oil and gas on the North Slope of the Brooks Range. They and the older rocks are bounded on the south by a zone of major thrust faulting. Folding related to the faults dominates Cretaceous structure in the southern section of the northern Chukchi Sea. From the Barrow arch northward, a thick sequence of bedded rocks dips to the north from the arch to the continental slope. The upper beds in this sequence are probably Tertiary in age and overlie the older rocks of probable Cretaceous origin. Several large diapir folds extend into the sequence, with some piercing the entire section up to the sea floor.

The Hope Basin is a broad structural depression that underlies a large portion of the Chukchi Sea off Point Hope. The basin was formed during Early to Mid-Tertiary time across a broad terrain of complex Paleozoic to Mesozoic sedimentary and volcanic rocks. The basin is probably entirely clastic and of mixed marine and nonmarine origin. The lower Tertiary sequence, up 1,500 meters thick, was later mildly faulted and folded. Subsequent deposition of a Pliocene to Pleistocene sequence took place reaching a maximum thickness of about one kilometer.[38]

The northern Chukchi Sea is underlain by some of the same geological strata and features that are present at Prudhoe Bay, the site of a giant oil and gas field, and the Naval Petroleum Reserve, site of several lesser oil and gas fields. Sedimentary deposits north of the Barrow arch may attain a thickness of 6,000 meters or more. The possibility that these deposits may represent a Late Cretaceous and Tertiary delta, in combination with the presence of diapiric structures, makes the area attractive for petroleum exploration. In the Hope Basin, the presence of a regional arch, many smaller folds, and numerous faults in the older sedimentary strata combined with a local erosional surface at the base of the younger strata, offers good oil and gas trapping potential.[39]

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[38] Final Environmental Statement, Proposed Increase in Oil and Gas Leasing on the Outer Continental Shelf. op. cit., p. 363–364.

In 1974, the State of Alaska estimated that the Hope Basin area contained recoverable oil reserves of 1.8 billion barrels and recoverable natural gas reserves of 13.0 trillion cubic feet. A Federal lease sale is tentatively scheduled for the Hope Basin area of the Chukchi Sea in December, 1978. The State's estimate of recoverable oil reserves in the Chukchi Sea is 6.6 billion barrels while the recoverable gas potential estimate is 33.0 trillion cubic feet.

Although much of the continental shelf of the Chukchi Sea has not been studied, potential geologic hazards appear to be earthquakes, lack of bottom sediment stability, and bottom scour by polar pack ice.

The Beaufort Sea continental shelf off Alaska is relatively narrow, varying in width from about 97 kilometers in the west to about 48 kilometers in the east. The outer edge of the shelf lies beneath 50 to 70 meters of water. The Beaufort shelf is dissected by several submarine valleys. The Barrow Sea valley is the largest of these wending northeastward off Point Barrow across the shelf into the Arctic Ocean Basin. Surface sediments on the Beaufort shelf are composed of a poorly sorted mixture of mud, sand, and gravel with the gravel content being the highest along the outer margin of the shelf.

The Beaufort Sea shelf and slope are underlain by a progradational sequence of Cretaceous marine and non-marine sedimentary rocks that dips gently to the north off the Barrow arch. On the east, the Cretaceous rocks are overlain by Tertiary marine and non-marine strata. Geologic structures are present in these rocks to the west of the mouth of the Canning River, but east of the Canning the rocks are thrown into folds with hundreds of meters of structural relief and, in some cases, tens of kilometers of strike length.

The Cretaceous rocks beneath the Beaufort Sea probably contain organic rich shales at their base as they do onshore. The sands higher in the Cretaceous section contain both oil and gas deposits onshore near the coast. It is also possible that some of the pre-Cretaceous rocks which contain oil at Prudhoe Bay may locally extend across the Barrow Arch and thus underlie the Beaufort shelf. While the Cretaceous and Tertiary rocks thicken seaward, the pre-Cretaceous rocks are found, in general, within the shoreline facies along the Barrow Arch and thicken southward. A conservative estimate of onshore data suggests that, if prospective pre-Cretaceous rocks are present on the Beaufort Shelf, they are of limited extent.[40]

The offshore seismic records do appear to indicate, however, that the producing Permian-Triassic sand at the giant Prudhoe Bay field will probably occur north of the field beneath the shelf. This reservoir sand disappears at a fault line running northwest to southeast across

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[39] Ibid., p. 365.
[40] Ibid. p. 368–370.

Prudhoe and it has not been determined if it again appears at some point to the north. Wells recently drilled or planned in the waters of Prudhoe Bay may give some indication as to the geological situation farther offshore, but this information will not be released because the tracts on which the tests are located lie adjacent to an area yet to be leased by the State of Alaska. It is not expected that another Prudhoe Bay field will be discovered offshore in the Beaufort Sea because the larger structures appear to be complexly faulted, thus limiting the size of the fields and making any oil difficult to find. The exploration target to the north will be not only the Permian-Triassic sand, but also Missisippian Pennsylvania strata and the younger Cretaceous sands.[41]

It is also possible that there is favorable hydrocarbon potential to the northeast of Prudhoe Bay as well as due north. To the east, the younger Mesozoic formations thicken though less is known about them. The area may be a gas province rather than oil province, however, as it lies in the direction of the Mackenzie Delta gas resources which are located about 325 kilometers further to the east.[42]

Onshore exploration on the North Slope has led to two recent discoveries with possible implications for offshore hydrocarbon prospects and have added to the reserves to be tapped by the trans-Alaska pipeline. One discovery was made three miles north of the Prudhoe Bay field on the shore of Gwydyr Bay in the same formation that is productive in the Prudhoe Bay structure. An earlier discovery of a new oil pool in the Prudhoe Bay field was directionally drilled out under the bay from an onshore site on the edge of Prudhoe Bay. The new pool will produce from Upper Paleozoic strata lying below the Permian-Triassic sand which is the principal pay zone in the Prudhoe Bay field.[43]

The Prudhoe Bay field currently has three wells on production with a total output of about 6,300 barrels of oil per day. The oil is used to supply the needs of the development of the field. Cumulative production of oil in the Prudhoe Bay field has been about 5.8 million barrels.[44] The field is scheduled to have some 130 wells which are expected to provide an output of about 1.2 million barrels per day when it goes on stream sometime in 1977. The production at that time is expected to average out to about 9,000 barrels of oil per day per well.[45]

Working to meet this goal, B. P. Alaska Inc., operator for the western portion of the field, has already drilled about 60 of the 70 wells that will be needed for its section. In the eastern section of the field, it is projected that about 60 wells will be needed when the field goes into production. Atlantic Richfield Co., the operator of the eastern section, has completed about 30 wells and is continuing the developmental drilling program.[46] The huge Prudhoe Bay field has been estimated to contain reserves of about 9.6 billion barrels of producible oil.[47]

A recent study projected recoverable oil reserves in the main reservoir (the Sadlerochit Formation) to range from 6.5 to 8.18 billion barrels depending upon a variety of production factors and secondary recovery techniques. The remaining reserves are estimated to be in other Permian-Triassic Formations (primarily the Sag River and Shublik) which are projected to contribute more than one billion barrels of oil to the ultimate recovery from the field.[48] The main Prudhoe Bay natural gas reserve has been estimated by State officials at more than 30 trillion cubic feet.[49]

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[41] Wilson, Howard M. Wildcatters Poised for Beaufort Sea. The Oil and Gas Journal, June 2, 1975, p. 100.

[42] Ibid., p. 102.

[43] Alaska. Offshore. June 20, 1975, p. 117.

[44] Prudhoe Bay Field Will Get 130 Wells by 1977 and 1.2 Million Barrels Per Day, Offshore, April 1975, p. 110.

[45] Ibid.

[46] Ibid.

[47] Two Pay Zones Not Included in Prudhoe Bay Study. The Oil and Gas Journal, December 29, 1975, p. 73.

The Navy's Petroleum Reserve Number 4, located at the northern tip of the United States about 58 kilometers west of the Prudhoe Bay unit boundary, is a largely unexplored untapped oil and gas province that may contain reserves rivaling those of Prudhoe Bay. With sporadic drilling during the past 30 years, the Navy has discovered a series of oil and gas fields. None, however, has been of commercial magnitude, by North Slope standards, except the small Barrow gas field which serves the local area. The Navy recently decided to hire an oil company to begin a systematic wildcat drilling effort. The Navy plan was to have resulted in a 26 well program over the next seven years, a pace quite slow by industry standards, but recent legislation will transfer control of the reserve from the Department of Defense to the Department of the Interior on June 1, 1977. Exploration will continue under the Department of the Interior and the area will be renamed the National Petroleum Reserve. Production is not expected to begin in the reserve until 1980.[50]

The cost of the seven year program to explore and partially develop the reserve had been estimated at between $400 and $500 million.[51] Test well drilling from 1944 to 1953 found a number of small fields, none large enough to warrant development other than for local use on the remote North Slope. The largest of the finds, the Simpson, Umiat, and Fish Creek fields, probably have reserves of about 100 million barrels of oil. The Gubik gas field, which lies about two-thirds outside of the reserve, has about 141 billion cubic feet of gas. The Barrow field has about 12 billion cubic feet of gas still unproduced.[52]

The Federal Government has estimated that the undiscovered resources of the reserve range from ten to 33 billion barrels of oil and up to 80 trillion cubic feet of gas. This estimate is based mostly on the prospect of finding within the reserve the same formations that are productive at Prudhoe Bay. The unknowns are, therefore, whether the sands are present and, if so, whether they contain producible oil. Much of the earlier drilling in the reserve has been to the Cretaceous rather than to the older Triassic, Permain, and Pennsylvanian rocks which are productive in Prudhoe Bay. There are large Cretaceous structures in the reserve which should be tested, but the Cretaceous thins out in the northern part of the reserve and the older formations thus become shallower and also should be tested early.[53]

The Navy drilled a $7 million dry hole in a first effort to determine if the prolific Triassic-Permian Prudhoe Bay trend extends westward into the reserve. The test well was found to be non-commercial in the Triassic-Permain and also in the other lower zones. There was some disappointment regarding this initial failure to find major accumulations of hydrocarbons in the reserve in the zones that are most productive at Prudhoe Bay, however, it did take six years and 12 wildcat wells to find the large Prudhoe Bay structure.[54]

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[48] Ibid.
[49] Alaska Ups Estimate of Its Gas Reserves. The Oil Daily, March 3, 1976.
[50] Elk Hills, Other NRP's to Flow Soon. The Oil and Gas Journal, April 12, 1976, p. 50.
[51] Wilson, Howard M. op. cit., p. 109.
[52] Ibid. p. 110.
[53] Ibid., p. 112.

A Federal lease sale in the Beaufort Sea has tentatively been scheduled for October 1977. However, the State of Alaska is planning a lease sale in the State waters of the Beaufort Sea sometime before the Federal sale. The State tracts to be leased lie between the Canning and Colville rivers and will generally be inside the barrier island chain. Some of the area to be leased lies close to Prudhoe Bay. Much of the area to be covered by the State sale can be slant drilled from the shore or from the barrier islands, but there is other acreage included which will require drilling in the sea or from the frozen water surface.

The potential geologic hazards involved in drilling in the Beaufort Sea are concentrated mainly in the nearshore zone. Here, coastal erosion, migration of longshore bars and barrier islands, sea ice grounding and scour, and permafrost will affect drilling and the location of pipelines and shore facilities.

In 1974 the State of Alaska estimated that the recoverable oil potential beneath the Bering Sea is 27.4 billion barrels and that the recoverable gas potential is 200 trillion cubic feet.

Onshore, in the Brooks Range section of the Arctic Slope, the northern half of the mountain range consists of Upper Devonian, Mississippian, Permian, and Triassic rocks which, while structurally complex, are not metamorphosed and conceivably could be petroliferous.[55] The southern half of the Brooks Range is composed chiefly of metamorphic and igneous rocks which are not considered to have hydrocarbon potential.

The southern section of the Arctic foothills contains rocks which are complexly folded and faulted. The Mesozoic rocks of this region are generally impermeable, but the possibility of discovering permeable Paleozoic limestone or sandstone at drillable depths appears to warrant further exploration in the southern foothills.[56] Oil shale has been found in both Triassic and Jurassic beds and fracturers filled with asphaltic material have been reported in Cretaceous rocks. These organic rich shales and the organic rich Mississippion carbonate rocks may be petroleum source beds for the area. There has been no extensive exploration as yet in the southern foothills.

The Northern Arctic foothills include most of the Colville geosyncline and are composed of Middle and Upper Cretaceous clastic sediments folded and faulted into rather broad and open structures. The area includes a portion the Naval Petroleum Reserve, an area in which exploration is underway. The reserve extends into the Arctic coastal plain and the plain also includes the Prudhoe Bay field in its entirety. Thus, the Arctic coastal plain is being extensively explored and the area favorable for petroleum exploration is estimated to cover 51,800 square kilometers.

The State of Alaska estimated in 1974 that the onshore areas of the North Slope contain a recoverable oil potential of 15.5 billion barrels and a recoverable gas potential of 41.8 trillion cubic feet.[57]

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[54] Navy's North Slope Test Dry. The Oil and Gas Journal, June 2, 1975, p. 47.
[55] Grye, George, op. cit. p. 63.
[56] Ibid. p. 64.
[57] Alaska Natural Gas Transportation System, op. cit., p. 55.

YUKON-PORCUPINE PROVINCE

The Yukon-Porcupine province is a triangular area of about 38,850 square kilometers bounded on the east by the Canadian border, on the northwest by the Porcupine River, and on the south by the Yukon River. The Kandik River flows through the southern part of the province. About 7,770 square kilometers of this area is believed to be covered by volcanic rocks.[58]

Several test wells about 160 kilometers east of the province in Canada have yielded natural gas under high pressure. The geologic setting of this Canadian area is very similar to that of the Yukon-Porcupine Province.[59] Other favorable indications for hydrocarbon discovery in the province include thick sections of marine sedimentary rocks which contain oil shale and other high organic rocks, reeflike carbonate structures, and other geologic structures which appear suitable for trapping oil. Unfavorable characteristics include the scarcity of reservoir type rocks as evidenced in surface exposures; the fact that many of the geologic structures are complicated and even breached; and past igneous activity which could have destroyed much of the oil. The exposed sedimentary rocks in the area represent nearly every period of geologic time and are very thick, with an estimated average thickness of about 11.280 meters. It has been suggested, however, that the area prospective for oil and gas is relatively small and lies between the Nation and the Kandik rivers.[60]

The State of Alaska, in their 1974 assessment, estimated that the potential for the Yukon-Kandik area is 1.7 billion barrels of recoverable oil and 11.4 trillion cubic feet of recoverable gas.[61]

ALASKAN OIL AND GAS RESERVE ESTIMATES

The cumulative hydrocarbon production derived from Alaska is given by the U.S. Geological Survey as 0.610 billion barrels of oil and 0.905 trillion cubic feet of gas.[62] About two-thirds of the oil and almost one-half of the gas was produced offshore. The Survey also has listed the demonstrated hydrocarbon reserves of Alaska at 10.107 billion barrels of oil (9.957 billion barrels onshore and 0.150 billion barrels offshore) and 31.867 trillion cubic feet of gas (31.722 trillion cubic feet onshore and 0.145 trillion cubic feet offshore).[63]

The latest estimate by the Geological Survey of the petroleum potential of onshore Alaska ranges between six and 19 billion barrels of undiscovered recoverable oil with a statistical mean of 12 billion barrels.[64] The low value of the estimate is the amount of oil associated with a 95 percent probability that there is at least this amount while the high value is the quantity associated with a five percent probability of the presence of the high amount. The offshore petroleum potential of Alaska is estimated by the Survey to range between three and 31 billion barrels of undiscovered recoverable oil resources (at the 95 and five percent probabilities) with a statistical mean of 15 billion barrels.[65]

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[58] Grye, George, op. cit., p. 66.

[59] Ibid.

[60] Ibid.

[61] Alaska Natural Gas Transportation System, op. cit., p. 55.

[62] Miller, Betty M., et al., Geological Estimates of Undiscovered Recoverable Oil and Gas Resources in the United States. U.S. Geological Survey Circular 725, Reston, Virginia, 1975, p. 28–31.

[63] Ibid.

[64] Ibid.

The survey's estimate of the onshore natural gas potential of Alaska ranges from 16 to 57 trillion cubic feet with a statistical mean of 32 trillion cubic feet. Offshore natural gas potential is estimated to range from eight to 80 trillion cubic feet with a statistical mean of 44 trillion cubic feet. Again, the low values are those associated with a 95 percent probability of occurrence and the high values are those associated with a five percent probability of occurrence.[66]

The State of Alaska estimated in 1974 that, onshore and offshore, a total of 86.6 billion barrels of oil and 469.4 trillion cubic feet of gas would ultimately be recovered in Alaska. These reserves include estimated discovered reserves and estimated undiscovered recoverable reserves. These undiscovered recoverable reserve estimates are broken down as follows: [67]

UNDISCOVERED RECOVERABLE HYDROCARBON RESOURCES

	Oil (billion barrels)	Gas (trillion cubic feet)
ONSHORE:		
North Slope	15.5	41.8
Yukon-Koyukuk	5.4	17.8
Bristol	.9	6.8
Yukon-Kandik	1.7	11.4
Copper	.2	1.2
Cook Inlet (onshore and offshore)	2.5	18.4
Other	.2	1.1
Subtotal	26.4	98.5
OFFSHORE:		
Beaufort	2.7	13.5
Chukchi	6.6	33.0
Hope	1.8	13.0
Bering Sea	27.4	200.0
Kodiak Island	2.4	17.5
Gulf of Alaska (onshore and offshore)	8.8	64.2
Subtotal	49.7	341.2
Total	76.1	439.7

It can be seen from the totals that the older State of Alaska estimates are consistently higher than the most recent undiscovered recoverable hydrocarbon resources estimates of the U.S. Geological Survey. In fact, the State estimates are quite consistent with 1974 Geological Survey estimates for Alaska made before the sharp reduction in overall Survey hydrocarbon resource projections of 1975. The 1975 lowered Survey estimates are more consistent with major oil company estimates. Four estimates of Alaskan hydrocarbon potential follow: [68]

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[65] Ibid.

[66] Ibid.

[67] Adapted from Alaska Natural Gas Transportation System, op. cit., p. 55.

[68] U.S.G.S. (1974) and Mobil data from: West, Jim. U.S. Oil Policy Riddle: "How Much Left to Find? The Oil and Gas Journal, September 16, 1974, p. 27.

FOUR ESTIMATES OF ALASKAN HYDROCARBON POTENTIAL

	Oil (billion barrels)	Gas (trillion cubic feet)
State of Alaska:		
Onshore	26.4	98.5
Offshore	49.7	341.2
USGS (1975):		
Onshore	6–19	16–57
Offshore	3–31	8–80
USGS (1974):		
Onshore	25–50	105–210
Offshore	30–60	170–340
Mobil Oil:		
Onshore	21	104
Offshore	20	105

The latest Geological Survey estimates as well as general industry projections of Alaskan hydrocarbon potential have recently been lowered. The use of more sophisticated methods of evaluation has resulted in a comparable reduction of oil and gas discovery expectations throughout the United States. The latest U.S. Geological Survey estimates are the product of the analysis of a large amount of fundamental data by geologists on the Survey staff. Sufficient data have been collected and analyzed to produce a balanced estimate of domestic oil and gas resources. These survey resource estimates are, of course, subject to revision as the methods are improved, more complete and reliable data are acquired, technologies change, economic conditions change, and as waters deeper than 200 meters are incorporated into the appraisals. The uncertainties involved in estimating undiscovered recoverable resources are emphasized by the use of ranges of values. The Survey estimates are conservative in that they do not include resources in water depths greater than 200 meters, they do not consider improvements in the historical average of 32 percent recovery of inplace oil, and they do not allow for higher prices of oil and gas. In the State of Alaska, whether the high or low estimates are used, much more oil remains to be discovered if exploration is encouraged. In any consideration of undiscovered hydrocarbons, the practical question is how much oil and gas can be found, rather than how much is left to be found. An uncaptured resource provides no benefits. The attractiveness of the Arctic lies in the possibility that it may yield oil and gas in larger accumulations than the lower 48 States onshore and, in that sense, the oil may be found and translated to large volume production more efficiently and even sooner than would be the case with the exploitation of numerous small marginal fields in the picked over provinces to the south.

ARCTIC EXPLORATION AND DRILLING TECHNOLOGY

According to the oil industry technology is not a real barrier to development of the polar regions. Over the years concepts that are announced one year appear the next year as detailed designs and a year or so after that move into the construction stage and are being put to use. On the leading edge of technology today are Arctic marine exploration, drilling, production, pipelining and environmental prediction systems.

Increased exploration activity in Arctic waters is placing renewed interest in projects such as AIDJEX (Arctic Ice Dynamics Joint Experiment) which tracks ice floes in an effort to develop a model of the Arctic ice and reliably predict the motion of ice pack when driven by various factors, such as atmospheric and marine conditions.[69] Advanced geophysical exploration techniques are being developed to probe Arctic areas. By using seismic interval velocity profiles, Gulf Oil Canada has been able to predict troublesome drilling areas and abnormally high pressures in the Mackenzie Delta in addition to reducing drilling costs through better utilization of bits and casing.[70] A specially designed combination of seismic, gravity and magnetic exploration techniques has been developed for use in the Bering Sea.[71] One of the world's most sophisticated geophysical research ships, the *Hollis Hedberg*, has been built with limited icebreaking capabilities for operating in Arctic waters.[72] The *Narwhal II*, a seismic exploration submarine has been designed for survey work in the Canadian Arctic. Another submarine, the 6-man *Ben Franklin*, was being refitted in Canada for oil exploration beneath the Arctic ice.[73]

Experience gained in Arctic exploration can also be transferred to Antarctica. After two years of work in the Beaufort Sea, the *Aquatic Explorer* is being ice-strengthened to conduct a reconnaissance seismic survey in the more hazardous Antarctic waters and plans are to run a continuous reflection profile completely circumnavigating Antarctica.[74]

The challenge of offshore drilling in ice-filled Arctic waters has led to several innovations and the development of new technology. Dome Petroleum Ltd. has developed a system which involves ice-strengthened drillships and support vessels for a 112-day drilling season in the Beaufort Sea.[75] Another design combining a drillship with an icebreaker hopes to attain six month drilling season capability depending on the area in which it is operating. This system utilizes a pneumatically induced pitching system (PIPS) which allows drilling while ice-breaking. PIPS consists of transferring the effective buoyancy from bow to stern in cycles by alternately evacuating water from tanks fore and aft to produce a pitching motion capable of breaking ice.[76]

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[69] The Oil Daily, Arctic Drilling Generates Interest in AIDJEX, May 4, 1976.

[70] Dumont, A. E., and V. S. Purdy, Use of Seismic Data Can Cut Arctic Drilling Costs. World Oil, January 1976, p. 71–74.

[71] Austin, C. T. and M. G. Hopkins, Alaska's Bering Sea Probed with 3-Method Survey. World Oil, February 1, 1976, p. 50–54.

[72] McNabb, Hollis Hedberg: A Sophisticated Researcher. The Oil and Gas Journal, April 26, 1976, p. 200–205.

[73] LaCerda, John. Submersibles Part of Deep Water Oil Search. Ocean Industry, October 1975, p. 64–65.

[74] The Oil and Gas Journal, Dallas Firm Proposes Antarctic Survey, August 18, 1975.

[75] Colpitts, M. J. International Report, Canada, Environmental Conditions Have Necessitated the Development of Innovative Offshore Technology, Ocean Industry, April 1976, p. 171–174.

[76] Jones, K. M. and J. C. Schaff, Icebreaking Drillship for Offshore Exploratory Drilling in the Arctic. Journal of Petroleum Technology, April, 1975, p. 433–444.

Photo by James E. Mielke

Glacier flowing down from the ice cap, Ellesmere Island, N.W.T., Canada. Glaciers entering the sea produce icebergs which are a hazard to shipping and offshore oil and gas operations in the polar regions.

Dynamically positioned drillships without special strengthening or ice-breaking capabilities have also been successfully used to drill in Arctic waters. The *Pelican* was first used off the coast of Labrador in 1973 after a conventional anchored vessel had failed. The dynamic positioning capabilities permitted the quick disconnection and reconnection of the vessel so that it could move off the well, if necessary, to avoid icebergs. If icebergs were smaller than one million tons, it was found they could usually be diverted by a standby supply vessel towing them away.[77] For larger icebergs, disconnection of the riser pipe was made when the iceberg was between 0.8 and 1.6 kilometers (½ to 1 mile) away. If the calculated draft of the iceberg was such that it could hit the blowout preventer (BOP), the disconnection of the riser was made below the BOP stack and a cement plug and appropriate retainers were used before disconnecting. In the case of failure of the dynamic positioning, a sequential automatic system can be triggered that closes all the valves and rams and disconnects the riser in 38 seconds just below the stack assembly; cutting the drillpipe if necessary.

Other offshore drilling technology developed for the Arctic includes an air-cushioned drill barge which can glide across the ice with an ice-melting positioning system to counteract ice movement while drilling.[78] Bottom mounted drill systems constructed of steel and/or concrete in the shapes of cylinders and conical monopods have been designed to embody icebreaking or ice-cutting capability.[79]

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[77] The Oil and Gas Journal. Drillship Eases Dangers From Icebergs. May 12, 1975, p. 38–40.

[78] Colpitts, op cit., p. 172.

[79] Ibid.

Another innovation that has been successful in the Arctic is offshore drilling from floating ice platforms. In areas where there is relatively little ice movement, platforms or rafts can be built up by pumping water onto the ice and allowing it to freeze in two to five centimeter layers. By this method drilling can be carried out from January to May using a small conventional land rig. In March 1974, the first Arctic offshore gas well was drilled by this method off the Sabine Peninsula, Melville Island. Because the thickness of the platform (about five meters) limits the size of the rig that can be used, this, in turn, limits the depth of hole that can be drilled to about 3,000 meters (10,000 feet).

Artificial earth filled islands have been used successfully as drilling platforms in shallow water areas of the Beaufort Sea. To date, Imperial Oil Ltd. has drilled eight exploratory wells from islands constructed in water depths ranging from 1.5 to 7.5 meters in the Beaufort Sea adjacent to the Mackenzie River delta.

Offshore platforms in the Arctic would be seriously hampered by ice growth in addition to the pressure of pack ice. Once ice has accumulated on a platform, the major problems would be keeping a floating platform on location, or in preventing a bottom supported platform from capsizing. Dynamic positioning would become ineffective because of the greatly increased horizontal forces operating against it.[80]

One mobile rig designed for Arctic waters would have the platform mounted above a large tank that would float nearly entirely submerged so that water and ice could wash over it. The drillstring, conductors and other pipework would run through a well in the center of the tank. Pumping water into and out of the tank would enable it to break up ice floes. If used for production, the tank could be used for oil storage. So far this idea is still only on paper.

Specialized onshore drilling equipment has also been designed for Arctic use. Several novel design concepts have been incorporated into a new drilling completion rig to increase its mobility. The rig is owned by Nabors Drilling, Ltd. and will be used at Prudhoe Bay.[81]

ARCTIC PIPELINE TRANSPORTATION TECHNOLOGY

Another area of technology development for resource exploitation under Arctic conditions is in pipeline construction. Construction is now underway on the trans-Alaska pipeline project for transporting crude oil from the North Slope to Valdez under the overall management of the Alyeska Pipeline Service Company. The pipeline has been designed for an initial throughput of 1.2 million barrels per day with an ultimate capacity of two million barrels per day. The metallurgy of the steel for the pipe has been carefully controlled to insure ductility under low Arctic temperature conditions. The welding is stringently controlled and the same metallurgical considerations have been incorporated into the field welding procedures.[82] Extreme temperature demands have spurred research on pipe corrosion coating materials resulting in the production of new materials that exceed prior standards of performance.[83]

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[80] The Oil and Gas Journal. Ice Growth will Hamper Arctic Offshore Platforms. April 21, 1975, p. 82–84.

[81] World Oil. Only Eight Loads are Needed to Move Unique Arctic Rig. October, 1975, p. 73–77.

[82] Smith, T. E. Pipeline Contractors Gain Arctic Construction Experience. The Oil and Gas Journal, February 23, 1976, p. 108–116.

Soil conditions along the pipeline are extremely variable. Basically, they can be grouped into two categories, thaw-stable and thaw-unstable. In thaw-stable regions, the pipeline can be buried as thawing will not affect the stability of the soil. However, in thaw-unstable or permafrost regions the pipeline must be elevated on vertical support members (VSM's) which are set deep enough to rest on permanently frozen soil. The design and construction of the VSM's represents the greatest deviation from normal pipeline construction practice. The VSM's will contain thermal radiators and the pipeline itself will be insulated to prevent heat transfer. Rigs have been developed specifically for drilling the holes for setting the VSM's. Because of the variability of subsurface soil conditions, three different drill types are being used.

The construction pad itself is a highly engineered innovation. There can be no stretching out of equipment over the Alaskan landscape. All work must be accomplished on a narrow construction pad (15 meters on a 16.5 meter or 54 foot right of way set by Congress) composed of 60 centimeters (24 inches) of select gravel or somewhat less if a mat of styrofoam is laid down first. The styrofoam serves as an insulator and is used mostly north of the Yukon. Because of unique subsurface conditions in one area, it was necessary to construct 760 meters of snow pad. Snow making equipment had to be imported and the snow hauled 50 kilometers to build the pad.[84]

Large diameter pipe was constructed for the Alaska pipeline. Because of route changes since the original 122 centimeter (48 inch) pipe was purchased in 1969, Alyeska had to purchase an additional 13 kilometers of pipe. The pipe was purchased from the same Japanese manufacturers at more than four times the original cost per pound. No American manufacturers bid on the job either in 1969 or in 1975.[85] U.S. Steel Corporation, however, has announced plans to complete construction, in 1978, of the Nation's first pipemill capable of fabricating arc-welded steel tubes as large as 48 inches in diameter.

One internal welding machine developed especially for the wide diameter trans-Alaska pipe is a diesel powered crawler called "Snoopy". It is capable of moving through long strings of line to do manual or semiautomatic back-welding. It may also be used for visual inspection of the pipeline before it is placed in service.

GAS PIPELINE PROPOSALS

In addition to the crude oil pipeline now under construction, plans are underway to build a gas pipeline to the Arctic. Much of the basic technology and construction techniques would be similar to those developed for the oil pipeline. The major controversy at present is over which gas pipeline proposal best serves the combination of interests involved. These interests include Canadian and American producers and consumers, environmental interests, and economic interests. Three groups have proposed routes for transporting gas south from Prudhoe Bay and two Canadian groups have proposed alternative pipeline routes from the Canadian Arctic.

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[83] Hancock, J. R. and H. C. Price. Improved Pipeline Coatings Emerge. The Oil and Gas Journal. May 10. 1976. p. 77–80.

[84] Smith. op. cit., p. 113.

[85] Wilson. H. M. Alyeska Playing Catch Up But Confident of Meeting Deadlines. The Oil and Gas Journal, June 2, 1975, p. 73–76.

The Arctic Gas consortium has conducted a large amount of research on the problems involved in gas pipeline transportation in the Arctic. Among their conclusions are that a pipeline is the most efficient and economic method of transporting gas in the Arctic and that refrigeration would make it possible to transport natural gas in the Arctic by conventionally buried pipelines. The system proposed would transport gas from Prudhoe Bay eastward to connect with a pipeline from the Mackenzie Delta and then bring the mixed Canadian and U.S. gas south through Canada into existing Canadian and American pipeline systems.

The system proposed by El Paso Natural Gas Co. involves the construction of a natural gas pipeline routed for the most part within the utilities corridor being used to construct the Alyeska oil pipeline to a liquefaction plant to be constructed on the south coast of Alaska. The liquefied natural gas (LNG) would then be transported by LNG tankers to facilities at Point Conception, California where it would be regasified and either sent eastward through pipelines already in existance or used to displace gas now being piped eastward.

A third route for moving gas from Prudhoe Bay has been proposed by Northwest Pipeline Corporation. This proposal would construct a pipeline parallel to the trans-Alaska crude line and the Alaska Highway to connect with existing pipeline systems in British Columbia and Alberta. Northwest is conducting environmental, technical, and engineering studies to support the proposed route.

A pipeline project to transport gas from Canada's Arctic Islands to its populous eastern provinces has been proposed by Polar Gas. Two alternate routes are under consideration: one on the east side of Hudson Bay and the other on the west side. The eastern line would be longer but would deliver gas directly to the eastern provinces whereas the western line would tie into existing pipelines near Winnipeg. A major technological challenge, not common to other pipeline proposals, would be the crossing of several channels between islands in the Arctic archipelago. The crossings will total less than 160 kilometers but will be in water as deep as 300 meters. Several methods of laying pipe across the channels have been considered. These methods include: (1) lowering the pipe from the ice surface; (2) pulling either from shore, from the surface of the ice or from a vessel; and (3) tunnelling which could be used on short crossings where approaches have already been tunnelled to protect against ice scour. Present indications are that the bottom-pull method might be the most efficient, utilizing a specially designed vessel for the longest crossing where the ice surface is least reliable, and pulling from artificial ice platforms on the channel ice for other crossings too long for shore to shore pulls.

Another all Canadian proposal is the Maple Leaf project of Foothills Pipelines, Inc. This proposal would bring natural gas from the Mackenzie Delta area to connecting lines in British Columbia and Alberta, along roughly the same route as the Arctic Gas proposal.

Unlike the Arctic Gas proposal the line would not extend to Prudhoe Bay.

TANKER TRANSPORTATION PROPOSALS

Several proposals have been made for transporting oil and gas from the Arctic. Some proposals utilize conventional tankers or LNG (liquefied natural gas) tankers and others would require the development of new technology. Among the conventional proposals are two for transporting gas from Cook Inlet to the west coast of the lower 48 States. Pacific Alaska LNG Company would construct pipelines and liquefaction and storage facilities near Kenai, Alaska and transport the LNG to facilities near Los Angeles. Approximately 145 kilometers of pipeline would be constructed in Alaska and would cross Cook Inlet. A second proposal by Marathon-Phillips LNG would transport LNG to Oregon from existing facilities at Nikiski, Alaska. The existing facilities have been in use since 1969 for liquefying natural gas for export to Japan. This proposal has been dropped after an unfavorable ruling by the Federal Power Commission (FPC) on the jurisdictional status of the proposal.

Several unconventional designs have been proposed for tankers to transport oil from Arctic waters. These designs can be separated into three basic types: surface, semi-submersible, and submarine. Of necessity, surface and semi-submersible tankers would require ice breaking capabilities. The idea of ice breaking tankers is relatively new. It developed as a result of the recent trend toward construction of larger tankers with a size and weight which coupled with the proper design could possibly be used for breaking ice.

Until 1969 relatively little was known about Arctic ice conditions and the ship designs necessary to operate in Arctic waters. In September of that year the 115,000-ton tanker *S.S. Manhattan*, financed and ice strengthened by Humble Oil and Refining Company (now Exxon), reached Prudhoe Bay from the east coast of the United States. The run was made with the help of Canadian and American icebreakers when the ice conditions were easiest. From further tests in April 1970 when ice conditions were much tougher, Exxon learned that icebreaking tankers would have to be larger (the *Manhattan* was considered a half-scale model); need a stronger hull, using heavier and more expensive steel; a redesigned bow; and about five times the power used on a conventional ship of comparable size.[86] While Exxon considered the experiment a success and stated that tanker transport from Prudhoe Bay was commercially feasible, pipeline transport had the economic edge. No further development work was done.

The feasibility of tanker transport would depend on where oil is found in the Arctic. Tankers would be a logical alternative if oil were found in the eastern part of the Canadian Arctic because the waters there are open for several months in summer and the ice is not heavy during the winter. On the other hand icebergs may be more of a problem in that area. The location of an oil discovery near a deepwater harbor would be another consideration. Much of the western North American Arctic is shallow, and an offshore terminal of some sort would have to be constructed. Such a terminal or offshore pipeline would run the risk of damage by grounding ice. Floating concrete terminals have been proposed for Arctic seas.[87] Among the technological developments making such designs possible are: (1) high strength concretes such as polymer—impregnated concrete (P.I.C.) which have high compressive strengths (15,000 to 20,000 psi) high tensile strengths (1,500 psi), and excellent abrasion resistance and durability, (2) new coatings such as dense polyurethane used on the USCG Polar class icebreakers to provide better abrasion resistance and reduce adhesion, (3) new methods of constructing large prestressed floating concrete structures such as were developed for use in the North Sea understanding of ice-structure interaction.

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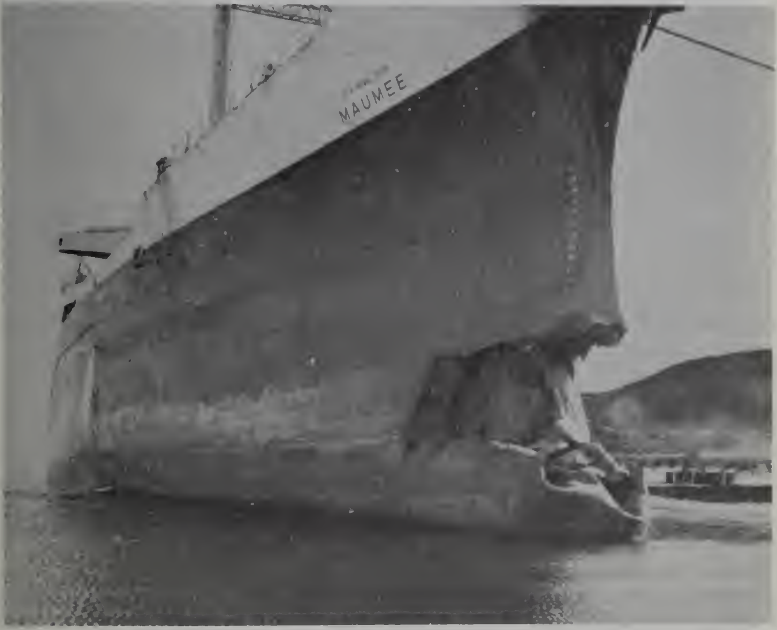
[86] Maxwell, Judith. Energy From the Arctic: Facts and Issues. Canadian-American Committee, 1973, p. 38.

While icebergs are a danger to tanker transport, there are safeguards available. Tankers calling at Valdez the southern terminous of the trans-Alaska pipeline, will have radar aids and USCG iceberg patrols to help avoid icebergs discharged from Columbia Glacier.[88] Although no safeguards are foolproof, it is also possible for tankers to survive collisions with ice and not release their cargo (Fig. 9).



U.S. Navy Photo

FIGURE 9.—Ice-damaged tanker. Ice-damaged Military Sealift Command tanker USNS *Maumee* at McMurdo Station on 26 January 1976. Despite a 5-meter gash in the double-hulled ship's bow, *Maumee* safely delivered about 15.9 million liters of liquid petroleum fuel products in an annual resupply of the U.S. antarctic program. The damage occurred on 21 January in heavy pack ice at 71°37′W. 177°46′E., in the northern Ross Sea about 725 kilometers north of McMurdo. Internal damage to the ship was limited to a water tank; none of the ship's cargo spilled into the sea. *Maumee*, escorted through McMurdo Sound by the U.S. Coast Guard icebreaker *Burton Island*, departed McMurdo on 29 January for repairs in the United States.

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[87] Gerwick, B. C., Jr. Floating Concrete Terminal For Arctic Seas. Ocean Industry. November 1975. p. 54–56.

[88] Science. Icebergs and Oil Tankers: USGS Glaciologists Are Concerned. November 14. 1975. p. 641–643.

A semisubmersible icebreaking tanker (SSIT) has been designed by the Norwegian Aker Group after five years of research. The SSIT has a submersible main hull with two superstructures located fore and aft and supported by narrow transition sections along the center line of the vessel. The vessel would perform as an icebreaker by forcing the ice upward and would require less power than a surface icebreaker. The bow of the double hulled SSIT is shaped like a conventional icebreaker for use when the vessel is in its most buoyant position. A 250,000 dwt SSIT should be capable of breaking ice up to 3.5 meters thick without having to resort to ramming.[89] The semisubmersible tankers have been proposed for use between Arctic locations and a transshipment point on Davis Strait off Greenland where conventional tankers could then be used more economically to continue southward.

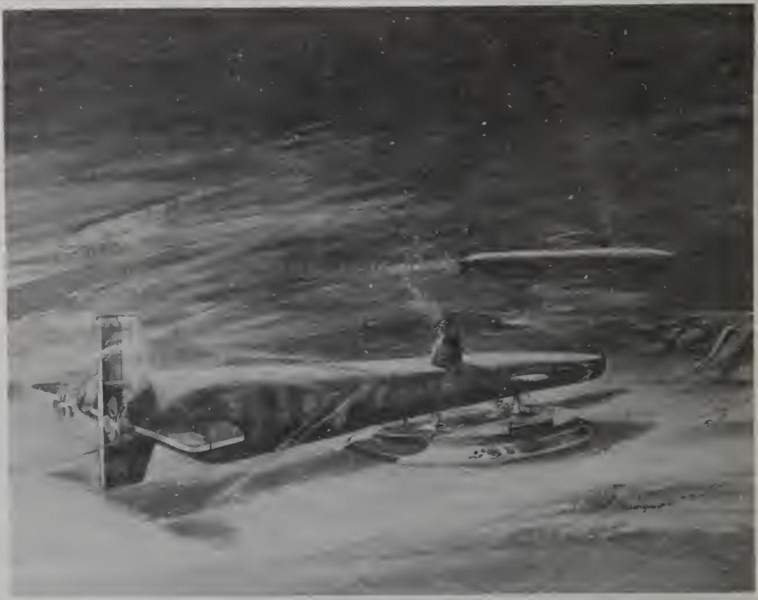

FIGURE 10.—Submarine tanker. In 1969 General Dynamics designed a nuclear-powered submarine tanker and proposed construction to several oil companies. The initial design called for a vessel 900-feet long—largest submarine ever built. Displacing over a quarter million tons when fully loaded, the submarine would traverse the Northwest Passage or the Arctic Ocean under the ice, carrying as much as 170,000 tons of Alaskan crude oil from the North Slope to the East Coast of the United States.

Courtesy: General Dynamics.

The third type of tanker that has been proposed for Arctic use is the submarine tanker. In 1969 General Dynamics announced the design of a 170,000-ton nuclear-powered submarine to transport oil from Prudhoe Bay under the ice to a transshipment port in Greenland or Newfoundland (Fig 10). The construction of a submarine tanker system was proposed to several major oil companies after extensive technical feasibility and cost evaluation studies showed the submarine to be a feasible and economically attractive means for moving Arctic oil. Although the oil companies became committed to a pipeline, the tanker proposal has the advantage of adjusting its route to service possible new oil discoveries in the Arctic Islands. The tanker was designed to be capable of being loaded either on the surface or while submerged. Because the water depth is shallow, a loading terminal would be constructed on the ocean floor about 80 kilometers off the coast of Alaska. According to a spokesman for General Dynamics, all the hardware exists for such a terminal, the only problem would be laying the submarine pipeline from shore to the terminal.[90]

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[89] Sandnaes, P. C. Icebreaking Tanker Designed For Arctic Use. The Oil and Gas Journal, December 1, 1975, p. 102–106.

Another subsurface transport system that has been proposed for Arctic transport is a controlled depth submerged barge.[91] Conoco designed a system that would have involved a 250,000 dwt barge towed by a powerful icebreaker to operate between Prudhoe Bay and a transfer point at Godthaab, Greenland. The theoretical design and model tests were completed and the next step would have been to build and operate a prototype of sufficient size to fully determine the operational costs. At one point Newport News Shipbuilding was also experimenting with a tug-barge concept that would permit surface and submarine operation for transporting oil between Alaska and the East Coast.[92] The tug would be a pusher-type with barges that join both end-to-end and stack on top of each other. The stacked barges would form a flat oval for use with the submarine tug or a separate surface tug could be used with other barge configurations.

OTHER TRANSPORTATION PROPOSALS

Rail transportation has also been studied as a possible method for bringing oil and gas from the Arctic. Two major routes have been suggested. One would run through the Yukon Territory connecting Prudhoe Bay with British Columbia and the United States. The other route would run east along the coast from Prudhoe Bay and down through the Mackenzie Valley. A Mackenzie route studied by the Canadian Institute of Guided Ground Transport determined that up to six million barrels of oil per day could be transported using unit trains on double (northbound and southbound) track. The line would terminate at Trout River, NWT near the 60 degree parallel where the oil would be transferred to a pipeline. A carousel terminal was designed where 15 tankcars could be unloaded at a time. The large construction costs, large demand for scarce gravel, and uncertainty about the environmental impact were problems raised. Cited among the benefits of a rail system would be the flexibility for transport of other resources, increased access and economic development of the northern areas. One study of pipeline, tanker, and rail transportation from the North Slope even states: "On economic grounds the Mackenzie Valley railroad is the superior system." [93]

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[90] Journal of Commerce, Submarine Tanker Held Competitive, October 27, 1970.

[91] Sudbury, J. D., Controlled Depth, Submerged Barge for Arctic Transport is Feasible and Economical. Offshore, August 1972, p. 47–50.

[92] Newport News Shipbuilding. Submarine Transport Project. Marine Systems Tomorrow, 1972, p. 7–9.

[93] Rice, R. A. How to Reach That North Slope Oil: Some Alternatives and Their Economics. Technology Review, June 1973, p. 8–18.

Aircraft have also been considered for transporting oil from the North Slope. Boeing Corporation proposed a giant resource carrying aircraft (RC–1) twice the size of a Boeing 747 jumbo jet.[94] The RC–1 would have two huge removable pods under each wing to carry oil or LNG. Each pod would be about the size of the fuselage of Boeing 747 giving the plane a capacity of 8,100 barrels of oil or 46 million cubic feet of LNG. The range would be about 2,700 kilometers. The southern terminus of the route would have a large aircraft maintenance base where the oil or gas would also be transferred to pipelines. Although the concept is interesting it has not had much success in attracting government or industry support, either in Canada or the United States. One concern is that if such an airplane crashed, the spill would likely create a difficult problem.

Another air transporter for oil or LNG once suggested by Arctic Helifloat Ltd. was a cross between a conventional plane, helicopter, and dirigible. Helium tanks 365 meters long at each end of a triple wing arrangement would supply lift. Two inboard cargo pods would carry a total of 22,000 barrels of oil and the craft would be propelled by 18 sets of rotary blades. Estimated range would be 4,800 km.

Arctic Canada

INTRODUCTION

The existence of petroleum in the Arctic region of Canada has been known since 1798 when Alexander Mackenzie recorded the presence of oil seeps along the banks of the large river which now bears his name. Around the turn of the present cenutry, other explorers recorded observations of oil and gas seeps on the northern shore of Great Slave Lake and near Fort Good Hope (See Figure 8). In 1920, a subsidiary of Imperial Oil Ltd. drilled the discovery well of the Norman Wells oil field in the general region of the seeps and the Canadian Arctic became an oil-producing area.[95]

With the exception of a flurry of development and production activity in the early 1940's, brought about by the demands of World War II, exploration activity in the Canadian Arctic has remained at a low ebb until recent years. The combinatoin of harsh climate, remoteness, lack of communications, and high development costs, resulted in a long period during which only limited exploration was conducted.

Recently, however, forecasts of supply and demand for Canadian oil and gas have demonstrated that substantial new reserves must be located and developed during the next two decades to satisfy the needs of expanding domestic markets and the requirements for exports. As a result, exploration is expanding into northern frontier regions, particularly into the Mackenzie Delta, the Beaufort Sea the Arctic Islands, and the Labrador Shelf to the southeast. Canadian oil production began to develop rapidly after the 1947 Le Due discovery in Alberta. Crude oil output reached a peak of 1.8 million barrels per day in 1973 and since has tapered off to the current level of about 1.5 million barrels per day. Exports of Canadian oil to the United States have dropped from 1.1 million barrels per day in 1973 to an estimated

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[94] Maxwell, op. cit. p. 40.

[95] Cleland, Noel A., Edgington, Anthony N., and Brusset, Michel J. The Economics of Developing Canadian Arctic Gas. Journal of Petroleum Technology, November 1974, p. 1199.

650,000 barrels per day in 1975. During the same period, gas exports to the U.S. have been reduced by about ten percent from the 1973 high of 2.8 billion cubic feet per day.

Canada's oil reserves continued to decrease in 1975, but natural gas reserves increased due, in part, to new discoveries in Alberta. The Canadian Petroleum Association estimates the country's remaining proved crude oil reserves at 6.653 billion barrels at the end of 1975, down 518.2 million barrels from 1974. This was the sixth consecutive year of decline and stemmed from a 1975 production of 502.8 million barrels of oil and a 15.4 million barrels loss in the gross-additions category.[96] A gain in the crude oil reserves in Saskatchewan was not enough to offset declines in most other provinces including Alberta, Canada's biggest producing province.

Canada's probable crude reserves, which include proved reserves under the Canadian system, were 7.832 billion barrels at the end of 1975, down 542.3 million barrels from the previous year.[97]

The remaining proved gas reserves, after a 1975 production of 2.361 trillion cubic feet, increased by 266.63 billion cubic feet to 56.974 trillion cubic feet. With the Arctic Islands included in the total for the first time, Canada's probable reserves of gas increased 7 trillion cubic feet to a total of 71.466 trillion. The Arctic Island reserves are not included in the proved category because the threshold volumes to justify a pipeline have not as yet been achieved. Mackenzie Delta gas reserves, on the other hand, are listed in both the proved and probable totals as the Canadian Petroleum Association assumes that delta gas production will be included in pipeline shipments from Alaska's Prudhoe Bay and thus no threshold volumes would be required. Probable gas reserves for the Arctic Islands, Mackenzie Delta and the balance of the Northwest Territories are given by the Association as 11.667 trillion cubic feet.[98]

In terms of a projected total resource base. the U.S. Geological Survey has estimated ultimate recoverable Canadian oil, both onshore and offshore, to amount to between ten and 100 billion barrels and the ultimate recoverable on and offshore gas to total between 100 and 1,000 trillion cubic feet.[99]

THE MACKENZIE DELTA

The Mackenzie Delta is a portion of the Beaufort (or Mackenzie) Basin that is a geographical and structural entity delineated by the Richardson Mountains and the Aklavik Range on the west and the Tuktoyaktuk Peninsula and Caribou Hills Escarpment to the east. The Mackenzie Basin is in some respects comparable with the U.S. Gulf Coast in that it consists of a thick sequence of Mesozoic and Cenozoic sediments (9,000 to 10,500 meters) deposited along the continental margin of North America. The sequence overlies older Paleozoic sedimentary rocks that now lie deeply buried in the central portions of the basin, but are exposed at the southern margin in a complex structural element called the Aklavik Arch. Oil and gas have been found in rocks ranging in age from Devonian to Late Tertiary.

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[96] Canadian Gas Reserves Rise. But Oil Falls Sharply in 1975. The Oil and Gas Journal. March 29, 1976, p. 63.

[97] Ibid.

[98] Ibid.

[99] Frezon. Sherwood E. Summary of 1972 Oil and Gas Statistics For Onshore and Offshore Areas of 151 Countries. Geological Survey Professional Paper 885, U.S. Government Printing Office, Washington D.C., 1974, p. 27.

The Mackenzie Delta Basin can be divided into two main exploration regions. The eastern region lies below the Tuktoyaktuk Peninsula and contains Lower Cretaceous reservoirs within rotated fault blocks. Oil has also been found in the underlying Jurassic and Devonian rocks. The other major exploration target is in the Upper Cretaceous and Tertiary deltaic sediments developed beneath the present-day Mackenzie Delta and adjacent offshore areas. The thick succession of nonmarine and marine sediments in this region is associated with gravity faults, diapirs, and other large related structures, resulting in high potential for hydrocarbon discoveries, especially gas.[100]

The outer delta Upper Cretaceous-Lower Tertiary prospects appear to have the best hydrocarbon potential. The inner delta Tuktoyaktuk Peninsula Devonian, Jurassic, and Lower Cretaceous rocks, which also been found to contain oil, are apparently much less prolific than outer delta rocks. Hydrocarbon source rocks are probably present in various parts of the thick section of sedimentary rocks. A Cretaceous bituminous marine shale, which is extraordinarily rich in organic matter and is the same deposit that is present on the Prudhoe Bay structure, is believed to be an important source of oil in the Cretaceous reservoirs of the region. The Devonian oil geochemically resembles the Devonian oil at Norman Wells 320 kilometers to the south along the Mackenzie River. The hydrocarbons in the Lower Tertiary reservoirs of the delta probably originated in the thick shale layers of equivalent age in the deep synclinal areas.

More than ten years of exploratory drilling of over 100 wells has resulted in the discovery of 15 possible oil and gas fields in the Mackenzie Delta region. The estimated cost of exploration in the area to date has been estimated at between $400 and $530 million.[101] Hydrocarbon discoveries in the delta have been made by Imperial Oil Ltd., the Gulf Oil Canada Ltd.—Mobile Oil exploration team, Shell Oil, and Sun Oil. Most of the discoveries are of natural gas. A few of the strikes are considered "significant" by their discoverers, which indicates in the guarded language of Far North disclosures, that the fields may be quite large. Other reservoirs, however, have already been declared noncommercial, generally because of low flow rates measured in the discovery wells.

Three gas fields on the delta are marked for development at a combined cost estimate at about $1 billion for wells and gas processing facilities.[102] The industry reports that proved gas reserves in the Mackenzie Delta—Beaufort Sea area range from 6.1 trillion cubic feet to 7.9 trillion cubic feet. There is no estimate available for proved oil reserves because of a lack of data.[103] The delta gas volume is far short of the 25 trillion cubic feet of some optimistic past projections for year end 1973. Nevertheless, the delta is considered by the operators to have achieved threshold gas reserves sufficiently large to help feed a pipeline to southern markets if and only if the region's output can be combined with gas production from Alaska's North Slope in a United States-Canadian joint venture gas pipeline.[104] Oil reserves in the delta are still a long way from pipeline threshold volumes, but a delta crude line is under study. Imperial Oil Ltd., which has made the most strikes on the delta, has stated that gas reserves of about 15 trillion cubic feet would be required to justify a gas pipeline to carry only delta gas to market.[105] This would require more time and money for drilling and would considerably delay the timing of gas delivery. In addition, the company says that the unit cost of tariff for a delta only line would probably be much higher than for a line carrying both North Slope and delta gas, resulting in a long term reduction in the reserves that could be economically developed.

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[100] Cleland, et al., op. cit., p. 1199–1200.
[101] West, Jim. Arctic Slump Bad News for Canada Energy Future. The Oil and Gas Journal, February 9, 1976, p. 28.
[102] Ibid., p. 29.
[103] Ibid.

Sun Oil feels that achieving a delta only pipeline would require the drilling of from 40 to 70 more wells during a period of from three to six years at a cost of $500 million (1975 dollars).[106]

The Beaufort-Delta Oil Project Ltd. has a delta crude oil pipeline under study should additional oil discoveries in the future justify its construction. Current projections envision a 30 to 36 inch line with a throughput of 200,000 to one million barrels per day which would cost from $2 to $4 billion. The oil reserves required to support such a pipeline are estimated at between 1.5 and 7.3 billion barrels.[107]

Both Shell Oil and Gulf Oil have made sizable reductions in their overall estimates of ultimate recoverable gas reserves in the delta region. Imperial Oil believes that most of the remaining potential for the region lies beneath the Beaufort Sea. Shell has reduced its estimate of potential delta reserves to 47 trillion cubic feet of gas from an earlier figure of 77 trillion. It also reduced its estimate of reserve additions possible by 1995 from 68.5 trillion cubic feet to 32 trillion cubic feet. Gulf reduced its estimate of ultimate potential reserves to 50 trillion cubic feet from an earlier estimate of 65 trillion cubic and its estimate of reserve additions by 1995 to 36.5 trillion cubic feet from 47.5 trillion cubic feet.[108]

In contrast, the Geological Survey of Canada estimated in 1973 that the Beaufort-Mackenzie area held potential gas reserves of 93.5 trillion cubic feet. This figure is down, however, from their 1972 estimate of 117.2 trillion cubic feet.[109] In 1973, the Canadian Society of Petroleum Geologists estimated the Beaufort-Mackenize area potential natural gas reserves at 64.0 trillion cubic feet.[110] The ultimate recoverable oil potential of the Beaufort-Mackenize region has been estimated by the Geological Survey of Canada (1973) to be 6.2 billion barrels.

The oil industry has estimated that about 2.5 billion barrels of oil will be discovered in the Beaufort-Mackenize Delta region by 1983, the year crude oil production is expected to begin.[111] The projection is based on the assumption that the crude oil pipeline will be completed by 1983. Proven reserves are projected to reach 3.8 billion barrels of oil by 1990 with some 2.7 barrels developed by that time. Imperial Oil discovered Ivik field in 1973 and estimated overall production of the discovery well from several zones to be between 5,000 and 10,000 barrels per day. Ivik thus became one of three recently discovered oil fields whose total reserves are believed to be in excess of the absolute minimum required for development in the region.[112] Shell Oil has discovered the large Niglinktak structure with announced reserves of approximately 80 million barrels of oil and one trillion cubic feet of natural gas.

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[104] Ibid.
[105] Ibid.
[106] Ibid.
[107] Ibid.
[108] Ibid.
[109] Cleland et al., op. cit., p. 1200.
[110] Ibid.
[111] Thobe. Susan. Canada: Inflated Costs. Shortages. Labor Emigration. and Political Problems Cause Offshore Activity Doldrums. Offshore. June 20, 1975, p. 141.

The land areas of the delta have been subjected to a fairly thorough search and, although onshore exploration will likely continue for a number of years, it is probable that the major exploration effort will shift to Beaufort Sea waters. Imperial Oil has already made a significant oil and gas discovery in the shallow waters of the sea and other operators are making plans to drill the Beaufort's first wildcats with mobile rigs.

THE BEAUFORT SEA

The Mackenzie Delta overlies only the emergent part of the Beaufort sedimentary basin which extends from the Aklavik Arch and the Richardson Mountains to the edge of the continental shelf 40 to 130 kilometers offshore. Except for wells drilled on artificial islands in shallow water along the outer border of the delta, no drilling has been done in the portion of the Beaufort Basin which underlies the Beaufort shelf. The entire area out to a water depth of 500 meters has, however, been leased to various oil companies, including most of the international majors.

Extensive geophysical surveys have been carried out on the Beaufort Shelf follow by the publication of their summarized results. The surveys have indicated that a maximum thickness of Mesozoic and Tertiary sediments is reached about 32 kilometers off the northwest shore line of the delta and the sedimentary section thins to about 4,500 meters along the shelf edge. It is considered possible that the Barrow or Beaufort arch of Devonian and older rocks may extend from the north coast of Alaska eastward across the shelf edge. In the deep part of the basin there is a large field of diapirs (domes of salt or shale several miles in diameter that pierce thousands of meters of Cretaceous to Tertiary strata or form the cores of anticlines). In addition to the diapiric structures beneath the continental shelf, there is a series of anticlines adjacent to the faults, which characterize the Upper Cretaceous and Tertiary hydrocarbon traps of the onshore delta, that persist seaward and could result in oil and gas accumulations in a succession of seaward prograding sand wedges.[113]

The Beaufort Sea is one of the world's most hostile environments for the exploration and development of oil and gas. The polar ice pack moves in upon the waters of the continental shelf and affected by powerful winds, tides, and currents mobile ice, subjected to shearings and the formation of pressure ridges, has been known to scour the sea bottom in waters up to 45 meters deep. Along the coast, landfast ice (ice held fast to the shore) often extends out to water depths of about

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[112] Ibid.

[113] King, Robert E. Canadian Arctic Promises Future Gas and Oil Supply. World Oil, December 1975, p. 56.

25 meters and is about two meters thick. In the spring, the landfast ice and mobile ice begin to break up and move far offshore with the polar pack, with much of the Beaufort Sea becoming open water by midsummer. Under favorable conditions, such open water can last from the end of July until the freeze-up in October. It is under open water conditions that offshore drilling with drill ships is expected to be carried out. However, if westerly winds prevail throughout most of the summer, as they frequently do, ice conditions will be heavy and drilling operations will be impossible.[114]

In early 1976, a report on drilling in the Beaufort Sea prepared jointly by industry and Canadian federal environmental specialists indicated that while the probability of a blowout is remote, cleanup operations could take a year or more, and Canadian environmental officials stated before a House of Commons committee that drilling in the open waters of the sea would require the posting of a $10 million cleanup bond.

The U.S. State Department has filed a note of concern regarding drilling in the Canadian portion of the Beaufort Sea and has asked for "full and adequate consultations" before a decision is made to begin. The U.S. Government is reportedly concerned about the impact of possible oil spills on the Department of the Interior plans for future lease sales in the U.S. sector of the sea off northern Alaska.[115]

Also opposed to present drilling are several native groups in northern Canada who have requested a delay on environmental grounds.[116]

Against this background, the Canadian cabinet postponed its final decision on the Beaufort Sea drilling project planned for this summer until April 15th when it decided to allow the project to proceed. The cabinet, however, imposed further restrictions on Dome Petroleum Ltd. and its partners including a deadline of September 15th to terminate offshore activities, which could mean that the two planned wells may not be completed during this year. Dome Petroleum Ltd. of Calgary and a subsidiary, Canmar Drilling Ltd., had first been given approval in principle by the Canadian government for the $150 million drilling project in 1974. The project calls for the drilling of two $35 million wildcat wells this summer using two ice-strengthened drillships. Dome has already spent an estimated $100 million on equipment and research and is required to drill this summer under farmout acreage agreements with several firms.[117] Since the original schedule of about 110 days will be cut almost in half by the cabinet's September 15th termination decision, the under utilization of the very expensive equipment will make the whole operation much more costly.[118] Another proviso of the federal cabinet was that the accident insurance requirement was raised from $10 million to $50 million or about $30 million more than the cost of a comparable indemnity coverage in the North Sea. Dome and its partners, Hunt International Petroleum Co. of Canada, Ltd.; Gulf Oil Canada, Ltd.; Aquitaine Co. of Canada,

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[114] Carter, Luther J. Oil Drilling in the Beaufort Sea: Leaving It to Luck and Technology. Science, v. 191, March 5, 1976, p. 930.

[115] Ottawa Delays Decision on Drilling in Beaufort Waters. The Oil and Gas Journal, March 29, 1976, p. 59.

[116] Ibid.

[117] Ibid.

[118] Kennedy, Tom, Calgary Elated Over Drilling OK. The Oil Daily, April 19, 1976.

Ltd.; and Mobil Oil Canada, Ltd. plan to spend about $400 million on 16 wells to be drilled in the Beaufort Sea between 1976 and 1980.[119]

Dome's fleet of two ice-strengthened drillships and five icebreaker supply petrol vessels are now undergoing sea trials and will be on station some 100 kilometers off the delta next July.[120] Dome has started construction of onshire facilities at Tuktoyaktuk near the mouth of the Mackenize River.

The Canadian department of northern development has been in favor of the drilling project, feeling that Dome is taking all possible precautions and that offshore drilling is needed to determine whether there is enough oil and gas in the western Arctic to justify Mackenzie Valley pipelines.[121]

THE ARCTIC ISLANDS

The Canadian Arctic Archipelago includes all of the islands north of the Canadian mainland and west of Greenland. Since the 1969 discovery of the first potentially commercial gas field in the Canadian Arctic, the exploration for hydrocarbons has greatly increased geological knowledge of the High Arctic.

The land area of the islands is 738,144 square kilometers. The area onshore and surrounding area offshore in which the sediments are thick enough to be attractive for hydrocarbon exploration is about 1,722,337 square kilometers including the offshore areas of the Arctic Coastal Plain.[122]

The sedimentary rocks of the Arctic Archipelago border the Canadian Precambrian Shield which is located to the east and south. In the south, a stable shelf area flanks the Precambrian rocks and is composed primarily of gently dipping early Paleozoic carbonate rocks. Further north is the Sverdrup Basin which is bounded on the south and east by the Parry Islands and Ellesmere Island fold belts and on the northwest by a long regional arch. The Sverdrup Basin is generally regarded as the Arctic Islands region having the best potential for hydrocarbon discoveries.

In fact, significant amounts of hydrocarbons in the Arctic Islands have thus far been found only in the Sverdrup Basin. The basin represents a broad trough that was developed in Late Paleozoic time and persisted as a site of rapid sediment deposition until the end of the Mesozoic.[123]

It is about 970 kilometers long from northeast to southwest, and is as much as 340 kilometers wide. Of the total area of about 312,000 square kilometers, about 60 percent is submerged beneath the sounds and channels between the islands. These waters are as much as 450 meters deep and are covered with ice most of the year.

From Proterozoic to Late Devonian time, an earlier trough evolved across the broad area from Melville Sound to the edge of the Arctic Ocean basin. In the southern part of this trough, which is now known as the Franklinian Geosyncline, a great thickness of Cambrian to

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[119] Ibid.

[120] Ibid.

[121] Carruthers, Jeffrey, U.S. Gets Last-minute Delay on Beaufort Sea Drilling. Weekly Energy Report, March 22, 1976, p. 11.

[122] Smith, J. H. Stuart and Wennekers, J. H. N. Arctic Islands: A Gas-prone Area. The Oil and Gas Journal. Part 1. March 8, 1976. pp. 95–96.

[123] King, Robert E., Canadian Arctic Promises Future Gas and Oil Supply. World Oil, December, 1975, p. 56.

Lower Devonian carbonates and black shales was deposited while in the north the rocks consist largely of shales interbedded with volcanics. An episode of folding and uplift began in Late Devonian and resulted in the formation of the Parry Island and Ellesmere fold belts north of Melville Sound and northeastward across Ellesmere Island; and intense folding, metamorphism, and plutonic intrusion in the rocks along the border of the Arctic Ocean. In Late Paleozoic time, the region northwest of the Parry Island fold belt collapsed to form the Sverdrup Basin. The sediments deposited in this basin during the Pennsylvanian and Permian were sandstones, shales, carbonates, and evaporites. The Mesozoic Triassic, Jurassic, and Cretaceous strata compromise a thick, nearly continuous sequence of predominantly nonmarine shallow water sands and shales.[124]

During the deposition of the younger rocks in the Sverdrup Basin, flowage of Pennsylvanian and Permain salt deposits was initiated by the increasing weight of the overburden, and numerous diapiric structures which vary widely in size developed in the central and northeast part of the basin. At the end of the Cretaceous, major downwarping of the Sverdrup Basin ended and the northwest border of the region was tilted to the northwest toward the Arctic Ocean basin. A complex pattern of faulting now divides the Sverdrup Basin and Parry Islands Fold Belt into a series of segments. While tensional stresses predominated in the central and western part of the Arctic Islands, compressional forces developed a fold belt in the northeastern Sverdrup Basin on western Ellesmere Island and on Axel Heiberg Island which resulted in a north-trending belt of narrow folds associated with numerous faults complicated by a large number of small diapiric intrusions.

The first wildcat well drilled in this region in 1969 proved a spectacular find, but the well blew out of control and was not capped for eight months creating a large hill of ice. The seventh well drilled in the High Arctic Islands also blew out, this time catching fire. The well blazed for months and was visible for hundreds of kilometers to passengers on trans-Polar flights. To the middle of 1975, 106 wells had been drilled in the Arctic Islands resulting in the discovery by Panorctic Oils, Ltd.; of six gas fields each with reserves estimated at more than one trillion cubic feet. There are also indications that an oil field of unknown size has been discovered. Total ultimate recoverable reserves of the six fields is expected to exceed 13 trillion cubic feet.[125]

The Thor, Kristoffer, and Wallis fields have only one well drilled in them while King Christian has two, but in some cases the structure can be defined at the surface. These four fields are located in the King Christian, Thor Island, southwestern Ellef Ringnes area. A second area, with reserves about equal to the first, is the Sabine Peninsula region of northern Melville Island which has two fields, Drake Point and Hecla. The Drake Point field is divided into the East and West Drake Point fields which are separated by a fault. The six gas fields have much in common in that they all: [126]

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[124] Ibid. p. 57.
[125] Smith, J. H. Stuart and Wennekers, J. H. N. Arctic Islands: A Gas-prone Area. The Oil and Gas Journal, Part 2, March 15, 1976, p. 148.
[126] Ibid. p. 150.

1. Are found in the western half of the Sverdrup Basin.
2. Have their major gas reserves in Upper Triassic to Lower Jurassic sandstones of an ancient delta complex.
3. Contain dry gas which is composed almost exclusively of methane.
4. Lie (with the exception of King Christian) partly or almost entirely offshore.
5. Are found (with the possible exception of the Hecla and Drake Point fields) solely in structural traps. (The Drake Point and Hecla fields may be partly, stratigraphic.)
6. None of the fields has major reserves in sedimentary rocks which lie below igneous sills or dikes.

Many of these similarities can be geologically explained. The offshore locations of the fields are a consequence of topographic inversion and erosion, probably within recent times.[127]

That all fields thus far discovered are in structural rather than in stratigraphic traps probably reflects the usual sequence of normal exploration when the obvious structures are drilled before the potential stratigraphic traps. The lack of major reserves in beds lying below igneous sills or dikes is a result of the selective intrusion of shales by the igneous rocks and the fact that the igneous intrusions decrease from east to west.[128]

Panarctic Oils, Ltd. is owned by 28 private Canadian companies and the federal Petro-Canada and remains the only active operator in the High Arctic Islands where, traditionally, exploration has been a cosmopolitan affair. Thus far about $500 million has been spent on the exploration of the oil and gas potential of the far north, divided almost equally between Panarctic and outside interests that have done their own drilling or have paid the Panarctic consortium to act as operator in their behalf. Panarctic is now maintaining three rigs in operation in the Arctic Islands, down from six in better times. Petro-Canada, the Canadian federal oil company, owns 45 percent of Panarctic and is considering investing additional funds in the Arctic region to increase the pace of oil and gas exploration.

In late 1975, Panarctic drilled an oil discovery well which, at the time, was expected to result in the first commercial crude oil production from the Canadian Arctic Islands. The wildcat, located on Cameron Island, flowed at a rate of 3,000 barrels per day of 43 degree gravity oil from Devonian rocks. The field was thought to have a production potential of 200 to 300 million barrels.[129]

Panarctic attempted to follow up the discovery with a distant hole to define the extent to the reservoir and was unsuccessful. The hole proved to be dry and now plans call for a return to the known structure to drill a hole only about six kilometers from the discovery well. Panarctic is also drilling in the Hecla gas field and has had success in establishing further gas reserves beneath the already known gas reserves of the field. Recent drilling could bring the proved gas reserves of the High Arctic Island area to nearly 20 trillion cubic feet as compared to an established gas reserve of between 12 and 15 trillion cubic feet at the end of 1975.[130]

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[127] Ibid.

[128] Ibid.

[129] Cameron Island Discovery Logs 3,000 Barrel-per-day Flow. The Oil and Gas Journal, October 27. 1975, p. 60.

[130] Kennedy, Tom, Cameron Island Well Big Disappointment. The Oil Daily, April 15, 1976. Note: Panartic recently put Arctic gas reserves at 15 trillion cubic feet. The Oil and Gas Journal, May 3, 1976, p. 114.

Various projections have been made of the ultimate potentially recoverable oil and gas reserves of the High Arctic Islands. Three of these estimates are as follows: Canadian Petroleum Association (1969) 43.5 billion barrels of oil and 260.7 trillion cubic feet of gas; Geological Survey of Canada (1973) 20.3 billion barrels of oil and 242.0 trillion cubic feet of gas; and the Canadian Society of Petroleum Geologists (1973) 23.9 billion barrels of oil and 195.0 trillion cubic feet of gas. Most of the figures were derived without regard for economics.[131]

Due to various geological factors, the hydrocarbon potential of the islands increases from east to west in both older and younger rocks and the most attractive potential structural and stratigraphic targets lie beneath interisland waters.[132]

Two future directions for exploration seem apparent. With between 15 and 20 trillion cubic feet of gas apparently already discovered, one objective would be to attain the necessary threshold reserves of gas (about 20 to 30 trillion cubic feet) to justify the construction of a 42 inch gas line to southern markets. If these reserves are not found reasonable rapidly, then liquefaction of the gas already found may be undertaken.[133]

Exploration will be concentrated in the Sverdrup Basin where the major gas finds are now located and it is expected that the drilling of offshore wells from ice islands or by other means will become more common. Well-completion techniques for underwater wells are available, but a major problem will be the method of laying gathering lines from the wellheads to the trunk lines on shore. This will be complicated by the movement of ice in the shallow waters around the islands and the resulting ice scouring of the sea floor.[134] Another major problem is that lower water temperatures will create the potential for plugging the offshore gas lines by hydrates, which will require either separation or methanol injection equipment at the underwater wellhead.[135]

A second Panarctic objective would be to continue the search for a giant oil field in the vicinity of the Cameron Island discovery. The importance of a commercial oil discovery by Panarctic could hardly be overstated especially under the prevailing circumstances of declining exploration in the Arctic Islands region. There is little likelihood of large scale foreign export of either oil or gas from the Arctic Islands and thus the cost of future development will have to be borne increasingly by Canadian public and private capital. All foreign funding (about $100 million mostly from U.S. interests) that provided an early and important source of cash for operations came to an end this year.

A modest reserve potential of perhaps 250 million barrels of recoverable oil on Cameron Island could allow Panarctic a means of producing very badly needed income. An average production rate of about 50,000 barrels per day, transported to market by icebreaker super tankers (yet to be designed and built), could give Panarctic about $70 to $80 million in annual net cash flow in contrast to its $38 million budget for this year.[136]

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[131] Smith, J. H. Stuart and Wennekers J. H. N., Part 2, op. cit., pp. 150–151.
[132] Ibid. p. 152.
[133] Ibid.
[134] Ibid.
[135] Ibid.
[136] Kennedy, Tom, op. cit.

Panarctic hopes that it can be marketing oil from the High Arctic by 1980 providing sufficient reserves are discovered soon.[137]

Photo by James E. Mielke

Pack ice off the Ellesmere Ice Shelf, Ellesmere Island, N.W.T., Canada. Pressure ridges of hummocked ice form where the floes have pressed against each other. The ridges may be several kilometers long, up to six meters high, and extend 30 meters below the surface. These ridges pose a technological problem for offshore oil and gas operations.

The Arctic Island region contains other prospective areas for oil and gas. The Banks Basin, a deep sedimentary embayment, lies between the western Sverdrup Basin and the Mackenzie-Beaufort Basin. Part of this basin lies onshore on Banks Island and it also extends west to the border of the continental shelf. The sedimentary rocks in the Banks Basin are mostly Cretaceous in age and overlie Devonian strata. Several wells have been drilled on Banks Island, but the drilling results have not been revealed.

Another prospective region with a thick sedimentary rock section is the seaward-thickening wedge of Tertiary clastics off the northwest shore of the Arctic Islands. After the cycle of sedimentation in the Sverdrup Basin ended in the Late Cretaceous, there was a strong northwestward tilting of the continental margin and a wedge of Tertiary sediments prograding toward the Arctic Ocean was deposited. The only information available on this rock section is from geophysical reconnaissance surveys, and its productive potential is unknown.[138] It has been assumed, however, that this Tertiary section may be in some degree comparable to the Tertiary sediments of the Mackenzie Delta. The region, out to the shelf edge of the Arctic Islands, is entirely under lease in spite of the fact that the shelf edge is at a depth of 500 meters and the continental shelf zone is permanently ice bound.

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[137] Ibid.

[138] King, Robert E., op. cit., p. 58.

Elsewhere in the Arctic Islands region, hydrocarbon potential is believed to exist in the belt of grabens which underlies McClure Strait and Melville and Lancaster Sounds. The grabens are filled with Upper Cretaceous and Tertiary sediments.[139]

THE LABRADOR SHELF

The formidable mountains of granite and metamorphic rocks which occur along the coast of Labrador give no indication of the existence of a deep sedimentary basin offshore. In 1964, however, geophysical surveys indicated the presence of up to 6,000 meters of sediments over a wide extent of the outer part of the Labrador Shelf as well as more than 3,000 meters of sediments off the coast of Baffin Island in the Davis Strait and Baffin Bay.[140] Subsequent geological sampling has shown that the sedimentary rocks off Labrador range in age from Jurassic or older to Late Tertiary. In recent years, the entire shelf off Labrador and Baffin Island has been leased to a number of oil companies and intensive geophysical work was been done. The first exploratory wells have been drilled and two gas condensate discoveries have been made.[141]

The rugged surface of the Precambrian shield of Labrador slopes seaward to a trench which is know as the Marginal Channel and is as much as 600 meters deep. Northeast of this trench, the sea floor rises to an outer continental shelf with a generally smooth surface, except in areas cut by gullies and deep channels. Most of the outer continental shelf is shallower than 200 meters, but the shelf edge is at 500 meters which contrasts with the 200 meter depth at the shelf break along the coast of the western North Atlantic southward from Newfoundland.[142]

The first well on the Labrador Shelf was drilled in 1971 to a depth of about 1,070 meters, but was abandoned prematurely due to bad weather. Drilling was not resumed until 1973, when the Eastcan group, a consortium of American and European oil companies, drilled a second wildcat about twice as deep near the earlier well. Another well was drilled about 200 kilometers northwest of the two dry holes to a depth of 2,475 meters. This test hole had indications of hydrocarbons, but was not tested. The onset of winter closed operations in 1973.

In 1974 a wildcat well was drilled about 250 kilometers southeast of the third well, which had the hydrocarbon shows. This well tested at a maximum flow rate of 20 million cubic feet of gas per day with some gas condensate probably produced from a Tertiary sand. Then the third well was tested and flowed at a rate of 13 million cubic feet of gas per day with gas condensate. It is now understood that the reservoir in this well is a Jurassic carbonate underlying a sheet of basic igneous rock.[143]

In 1975, Eastcan returned to the Labrador Shelf with two rigs to begin a program of evaluating widely separate areas along the entire extent of the shelf to as far north as Hudson Strait. By October one of the wells had been abandoned, two suspended, and the fourth was drilling. The two suspended wells had good shows of hydrocarbons. On the basis of the 1974 and 1975 drilling, AGIP, a partner in the

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[139] Ibid.
[140] Ibid.
[141] Ibid.
[142] Ibid.
[143] Ibid. p. 59.

Eastcan group, announced that a new hydrocarbon province had been discovered on the Labrador Shelf.[144]

Another wildcat off Labrador will be drilled by British Petroleum. Chevron and Gulf oil companies both have acquired interests in British Petroleum's offshore Labrador permit block of 13 million acres.

The Labrador Shelf contains more than 1,500,000 cubic kilometers of prospective sedimentary rocks. After two significant gas discoveries in this large area and unevaluated hydrocarbon shows in other wells, future prospects are very encouraging, though gas may predominate over oil.[145]

Whether the hydrocarbon prospects are better than those of the Grand Banks and the Scotian Shelf further south, where about 100 wells have been drilled without confirmation of a commercial discovery, remains to be determined by future exploratory drilling.

The Labrador Shelf poses extremely severe operational problems. The water above the shelf is quite deep and the shelf is separated from the mainland by an even deeper marginal channel. Icebergs drifting south from Davis Strait are always a hazard and floe ice is present for as much as three months of the year. Such operational hazards are expected to delay full development of the Labrador Shelf for many years.[146]

The ultimate recoverable oil potential for the entire offshore east coast of Canada has been estimated at 47.5 billion barrels by the Geological Survey of Canada (1973) and at 24.8 billion barrels by the Canadian Petroleum Association (1969).[147] Ultimate recoverable gas potential of the east coast offshore is projected at 307.1 trillion cubic feet by the Geological Survey of Canada (1973) and at 149.9 trillion cubic feet by the Canadian Petroleum Association (1969).[148]

CANADIAN OIL POLICY

Canada operates its Government under the British North American Act, which is about 100 years old. The act calls for a division of authority between the Federal Government and the provincial governments with any unspecified authority delegated to the Federal Government. Now, 100 years later there is conflict between provincial and federal powers regarding ultimate governmental authority. This present internal dispute, coupled with the changes in the world price for oil, has altered the prospects for oil exploration in Canada.[149]

Thirty years ago, Canada was almost completely dependent upon outside sources for its oil and gas requirements. Then, between 1947 and 1970, Canada discovered enough oil and gas to become self-sufficient in both. The major role in the discovery and development of these hydrocarbon resources was played by the international oil companies.[150]

Canada produced oil and gas for its own consumption from Toronto west to Vancouver, leaving about 45 percent of its population east of Toronto dependent upon imports. Generally, it sold about as much domestic oil as it consumed and bought about the same amount it sold

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[144] Ibid.

[145] Ibid.

[146] Ibid.

[147] In '76 . . . Canadian Drillers Will Concentrate on Alberta. World Oil, February 15, 1976, p. 106.

[148] Ibid.

[149] Canada's Oil Policy: The Tip of the Iceberg, Offshore, December, 1975, p. 67.

[150] Ibid.

(to the U.S.) from Venezuela and the Middle East for import and use east of Toronto.[151] The oil and gas companies prospered and reinvested in the exploration for new hydrocarbon reserves inside Canada.

However, when the world price for oil began its steep increase in the 1970's, the Canadian government, to protect the Canadian consumer, froze the price of Canadian crude, but started selling its export crude at world prices through the levying of an export tax amounting to the difference between the frozen domestic wellhead price and the existing world price. Thus, the oil industry, the producing provinces (through lower royalty interests) and those countries importing Canadian oil were, in effect, subsidizing the consumers in Eastern Canada. Also, both the federal and provincial governments imposed higher royalties, withdrew tax incentives, and changed a number of land regulations in order to maintain their income.[152]

As the dispute between the federal and provincial governments increased, the higher royalties imposed by the provincial governments (the owners of the petroleum and natural gas rights) were countered by the federal Government which lowered industry tax writeoffs, imposed export taxes, and taxed royalties as income in order to protect itself against a decrease in federal revenues. The federal Government also insisted on the largest part of the offshore share, by limiting the offshore boundary of the provinces.

The companies caught between the actions, taken by the federal and provincial government experienced reduced earnings which translates into reduced incentive to explore. If this trend continues, the country may not develop its sources soon enough to fit its needs, much less a surplus for export. Canada needs to develop new reserves to replace the oil and gas which it is consuming. The country is currently producing considerably less than it uses and each year the deficiency grows.[153]

Canada is depending heavily on the Arctic frontier for new supplies of oil and gas. It is possible, however, that the new supplies which have been discovered can't be brought on stream quickly enough to avert serious shortages of energy. Forecasts of impending Canadian shortages take into account the scheduled phaseout of Canadian oil shipments to the United States to conserve supplies for use at home.

The extremely high operating costs and the impact of federal and provincial energy policies have slowed exploration in the Canadian Arctic in the past two to three years.[154] The number of active rigs is about one-half the number working in 1973 and the number of seismic crews is also down to about one-half the 1973 number. The result has been a drop in the number of discovery wells drilled each year on the delta and in the islands.[155]

Also impacting on Canada's energy future is the fact that drilling in established producing areas has not succeeded in replacing production with new reserves and supplemental supplies of energy such as the Athabasca tar sands in Alberta are not being developed as rapidly as was expected. The Canadian oil industry appears to require new and definitive policy decisions from the federal Government in the area of Arctic exploration. The federal Government has been working on a new leasing policy for frontier lands for more than four years nad the industry is waiting for the disclosure of this new policy so that it will know the ground rules under which it will have to operate in the northern frontier as wel as in other areas of federal land holding.[156]

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[151] Ibid.
[152] Ibid.
[153] Ibid.
[154] West, Jim, op. cit., p. 27.
[155] Ibid.

Against this background, the Canadian Government just recently abandoned its goal of energy self-sufficiency by the early 1980's for the more modest one of "self-reliance." Self-reliance is defined as reducing dependence on foreign oil as much as possible by increasing domestic supplies and stressing conservation. The Government stated for the first time that energy prices must increase sharply in the next two years to provide the exploration money which is needed by the oil industry. The Government did not give specifics as far as price targets, but indicated a move toward world prices, perhaps to $13 per barrel by 1978 from the current $8 per barrel. The Government also plans to increase natural gas prices to an appropriate competitive position in the next two to four years. The Canadian federal Government projects a reduction in dependence on imported oil by 1985 to one-third of consumption, compared to one-half in 1975. The new policy also includes a doubling of exploration and development spending in the northern frontier during the next three years from the current $350 million to $700 million.[157]

Canadian Government officials feel that $13 per barrel oil and a matching price for gas would make pipelines from the Mackenzie Delta and the Arctic Islands feasible. They believe that if prices remain at current levels, with increases only for inflation, no northern pipelines will be built.[158] This would lead to a growing shortage of oil and natural gas during the next 15 years. The Government, however, has still to detail the specifics of the new northern land regulations or the manner in which the increased revenue from the higher prices will be divided between the Government and the industry so as to encourage exploration and development and promote conservation.[159]

GREENLAND

Seismic studies off Greenland have resulted in encouraging indications of potential oil reserves. One area of promise lies off the southwest coast, where organic shales with source rock potential outcrop and where water depths are within reach of current offshore drilling technology. The Danish Government offered the southwestern offshore area of Greenland in the Davis Strait for leasing in 1974 and in the Spring of 1975 awarded 46 oil and gas leases totalling about 18,200 square kilometers to six exploration groups composed of 20 oil companies. The terms of the leases are considered stringent, causing doubt that the area will quickly experience drilling on a large scale.[160] The Danish Government will receive 12.5 percent royalties, up to 50 percent participation, and a 55 percent profits tax on any production.

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[156] Ibid. p. 32.

[157] Canada Junks Goal of Self-sufficiency. The Oil and Gas Journal, May 3, 1976, p. 130.

[158] Ibid.

[159] Ibid.

[160] Blocks Off Greenland Are Leased by Danes to 20 Companies. Offshore, June 5, 1975, p. 43.

In spite of the high cost to the oil companies and the severe operating condition the Ministry for Greenland expects the exploration groups to spend approximately $100 million during the first three to four years of operations and at least $300 million during the 16 year exploration period.[161] Depending on approval by the Danish Government drilling about 110 kilometers off western Greenland is scheduled to begin about May 15, 1976. The first test hole will be drilled by T.G.A. Grepco, a Canadian-French-Danish group in about 180 meters of water—Total, a French oil company, will be operator.[162]

NORWAY

It is apparent, after a decade of deep drilling, that the North Sea is one of the world's major petroleum provinces. Recent preliminary evaluations of hydrocarbons have indicated potential reserves which exceed 40 billion barrels of oil and 100 trillion cubic feet of natural gas. Several major structures have not as yet been drilled and many stratigraphic traps, indicated by seismic surveys, may contain sufficient hydrocarbons to allow eventual exploitations as small fields.[163]

The discovery of the large Groningen gas field in 1959 on the Netherlands coast focused attention on the North Sea as a potential petroleum province, causing a degree of urgency to subdivide this large tract of continental shelf. Agreements between the circum-North Sea countries were finally reached in 1965 and 1966. The division to 62 degrees north latitude resulted in Norway receiving approximately 131,000 square kilometers (about 27 percent) of the divided shelf area. In the far North, however, agreement with the Soviet Union has not been reached. Norway's position is based on the "middle line principal" as established in the 1958 Geneva Convention, while the Soviets appear to favor the "sector principal" which, in spite of a deviation around Spitsbergen, would result in Kremlin sovereignty over an additional 150,000 square kilometers of continued shelf.[164]

The status of Spitsbergen is also an issue. In 1920, the Treaty of Spitsbergen (signed by the Soviet Union and the United States, among other nations) granted sovereignty over the island group to Norway. If it had not been for the discovery of oil in the North Sea, Spitsbergen would not have become a problem. However, under the terms of the 1920 treaty, Western oil operations could take place around the islands. The Soviet Union is expected to oppose Western oil activity in the area because of its great strategic importance in allowing ships from the giant Soviet naval base at Murmansk ice free access to European waters.[165]

The first major North Sea discovery was made at Ekofisk in Norwegian waters in 1969. Ekofisk is estimated to contain 2.63 billion barrels of oil while the more recently discovered Statfjord field to the north (above 60 degrees north latitude) is reported to be the fourth largest offshore field in the world, with an estimated three billion barrels of in-place oil.[166] Also located above 60 degrees north is the Odin field which is estimated to contain a trillion cubic feet of gas.

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[161] Ibid.

[162] Search for Oil off Greenland to Start May 15. The Oil Daily, March 25. 1976.

[163] Thomas, Trevor M. Search for Hydrocarbons in Shelf Areas of Northwestern Europe: Progress and Prospects. American Association of Petroleum Geologists Bulletin, v. 59, n. 4, April 1975. p. 573.

[164] Kamer, Hansrudolf. Norway and the U.S.S.R. Square Off in the Arctic, Swiss Review of World Affairs, v. 24, n. 6, September 1974, p. 4.

[165] Norwegians See Threat to Isles. New York Times, November 25, 1974.

Oil tankered from Ekofisk now exceeds Norway's daily demand, causing the country to become an exporter of oil. The Norweigian Government at first tended to downplay the importance of North Sea oil, but is now stressing the value of the oil revenues for the future of the country and has stated that Norway can expect oil activity to continue for at least 100 years.[167]

The Norwegian Petroleum Directorate estimates Norwegian potential reserves south of 62 degrees north to be between 23 and 30 billion barrels of oil equivalents, with oil and gas in roughly even quantities. Of this potential, about 7.4 billion barrels of oil equivalents have been measured as commercially exploitable.

The U.S. Geological Survey has estimated that while the ultimate recoverable resources of oil and gas onshore in Norway are zero. There is a projected ten to 100 billion barrels of oil and ten to 100 trillion cubic feet of natural gas on the Norwegian continental shelf.[168]

The Norwegian Petroleum Directorate has established that the sedimentary rock volumes of the Norwegian shelf north of 62 degrees up to Svalbard indicate that this Arctic region may contain ten times as much petroleum and natural gas as the shelf to the south of 62 degrees. This projection is based on extensive geophysical and geological research that has been underway since 1968 under the auspices of the Norweigan Council for Industry and Scientific Research. The work has included aeromagnetic surveys, shipborne magnetic traverses, and refraction and reflection seismic coverage. The Norwegian Government estimates that its oil and gas deposits are so large that, if exploited only for domestic consumption at the present rate of about 67.5 million barrels of oil equivalents per year, the reserves would last for hundreds or perhaps even for thousands of years. However, the duration of the reserves will also depend upon the rate of export.[169]

In 1974, the Norwegian Petroleum Directorate intensified geophysical investigations north of 62 degrees north latitude. A total of 13,100 kilometers of reflection seismic profiling was performed in addition to the 18,300 kilometers surveyed during the five previous years. Magnetic and gravimetric recordings were taken simultaneously with the seismic work. The geophyhical investigations concentrated on four regions, off More-Lofoten, off Troms, off Finnmark, and in the Barrents Sea.[170]

In the More-Lofoten area 3,000 line kilometers of seismic profiles were added to the previous 9,650 kilometers already run, particularly to correlate the findings with the better known sections of the North Sea. The information gained was also needed to investigate the deeper parts of the shelf such as the Voring Plateau. The structural and stratigraphic features of this region are in general similar to those farther south, however there are also differences and it can not be taken for granted that the same geological conditions will prevail to the north.

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[166] Norway's Decade as a North Sea Power. The Oil Daily, May 6, 1975.

[167] International Report: Norway. Ocean Industry, April 1975, p. 131.

[168] Frezon, Sherwood E., Summary of 1972 Oil and Gas Statistics for Onshore and Offshore Areas of 151 Countries. Geological Survey Professional Paper 885, U.S. Government Printing Office, Washington D.C., 1974, p. 105.

[169] Ibid.

[170] Hagemann, Fredrik and Al-Kasim, Farouk Norway North of 62 Degrees North. The American Association of Petroleum Geologists v. 59/10 October 1975, p. 1827.

In the Troms area, a regional survey was performed with about 6,000 kilometers of seismic profiles being run. The 1974 investigations were of a detailed nature in order to select a location for initial drilling.[171]

The investigations off Finnmark were a direct continuation to the east of the large scale Troms survey of 1973. The survey amounted to a total of 3,200 kilometers, preliminary results of which indicate similar geologic development as in the west.[172] Several seismic lines have been run in the Norwegian section of the Barents Sea. The survey in 1974 totaled 3,200 kilometers.

As a supplement to the geophysical investigations and to assist in locating areas for initial drilling, two geochemical surveys were carried out off Troms. Gas chromatography, ultraviolet-induced fluoresscene, and partial pyrolysis were utilized to obtain indicator values from the near-surface sediments.[173]

The first drilling north of 62 degrees is planned for the spring of 1977 in the area where the North Sea becomes the Norwegian Sea. The Norwegian Government has picked the two most promising areas (based on results of the geophysical and geochemical investigations) and has indicated that concessions will be granted in time for drilling to begin in 1977.[174]

North of the North Sea, Norway's continental shelf is relatively narrow up to the Arctic Circle where it widens. Although up to 7,000 meters of sediments have been measured by seismic means in the more southerly area, water depths are somewhat beyond present capabilities. The axis of the sedimentary basin that has proven so prolific in the northern North Sea extends into this relatively deep water region before bending back into more shallow seas.

Surveys between 62 degrees and 65 degrees have shown up to 4,100 meters of sedimentary rocks only about 100 kilometers offshore, but the axis of the basin is around 200 kilometers offshore. Further out and beyond the continental shelf proper is the Voring Plateau. Recent estimates have indicated that the Voring and the nearby Helgeland basins together could contain a total of 30 billion barrels of oil or its equivalent in natural gas.[175]

In Deep Sea Drilling Project cores, traces of oil were found in the Miocene rocks of the Voring Plateau, but it will probably be a number of years until this area is drilled again.

The Norwegians have decided to first allocate tracts in the far north shelf, above the Arctic Circle. Two areas have been chosen, one in the Troms and the Hammerfest basins and the other in the Harstad basin. Both have been extensively surveyed, with the more detailed of the seismic work being used to locate potential drill sites. Of the two areas, the Troms and Hammerfest basins will probably be drilled first.[176] When concessions are granted, it is expected that the Norwegian State Oil Company, Statoil, which has had access to all survey results, will become a partner in all blocks. There will be 20 blocks in the Troms and Hammerfest basins covering a total of 7,500 square kilometers. The Hardstad basin area will be comprised of 15 blocks and also total 7,500 square kilometers.

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[171] Ibid.

[172] Ibid.

[173] Ibid.

[174] Cranfield, John. Norwegians Gear Up for Drilling North of 62nd. Ocean Industry, February 1976, p 111.

[175] Ibid.

[176] Ibid.

Both areas have favorable seismic refraction profiles. Metamorphic rocks underlie Mesozoic sedimentary rocks in steep sided basins which contain up to 5,000 meters of sediments fairly close to land.

Although the Harstad basin will probably not be drilled first, it may be the better geological prospect. Tertiary sediments in this basin are up to 2,000 meters thick while the Mesozoic reaches 4,000 meters in thickness in some areas. The most prospective rock units would be Lower Tertiary and Jurassic strata. There are, however, problems in this basis as it contains the Malang Shoal, a prime fishing ground.[177]

To the south of the Harstad basin is Andoya Island on which several wells have been drilled. Non-commercial hydrocarbons have been found in Cretaceous and Jurassic rocks which extend offshore as part of a continuous sedimentary basin that stretches between Norway and Spitsbergen. Results from the investigations on Andoya are positive indications of petroleum potential for the Harstad basin and drilling on Spitsbergen has also produced non-commercial hydrocarbons in strata of similar age.[178]

Future activities further south have not as yet been determined. The British government is calling for new licenses on several parts of its shelf, but the sector north of 62 degrees is specifically excluded as it has not as yet been designated an exploration area. In any event, British Petroleum activity cannot extend very much further north, being pinched out by Norway and the median line (not agreed on as yet) between Britain and Faeroe. The Norwegian shelf expands somewhat at this point, while the British shelf terminates in deeper waters.

The Barents Sea forms the northwesternmost part of the Eurasian continental shelf. To the east there is the Kara Sea and to the south the Eurasian continental landmass. The Barents Sea is underlain by sedimentary rocks of varying thicknesses and physical properties. The North Sea basin is known to extend north along the continental margin off Norway and the geophysical data from the Barents Sea may be interpreted to reflect a somewhat similar sedimentary environment. There is one major difference, however, in that the thick Tertiary rock sequence which is present in the North Sea and along the major portion of the Norwegian margin is found only as a wedge near the western margin of the Barents Sea.[179]

Folded structures of both regional and local extent occur in the Barents Sea subsurface as well as areas of faulting. At the current stage of the investigations, hydrocarbon prospects are promising and further study is warranted.[180]

What is now needed is the drilling of stratigraphic tests to correlate the geophysics and the geology and to obtain preliminary information about such physical properties of sedimentary rocks as porosity and permeability.

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[177] Ibid. p. 112.

[178] Ibid.

[179] Eldholm, Olav, and Sundvor, Eirik, Barens Sea—Geological and Geophysical Framework. The Oil and Gas Journal, July 28, 1975, p. 177.

[180] Ibid.

SWEDEN

Sweden has discovered oil on the island of Gotland (located well below the Arctic Circle) in the Baltic Sea. Petroleum has been discovered both on the island and also offshore from the island. The potentially productive geological structures discovered onshore apparently extend under the seabed to the east of the island. Swedish officials have stated that a recent offshore discovery is commercially exploitable with a potential production of 40,000 barrels per day. If actually developed, this would be the first Swedish domestic oil production.

At about the beginning of the decade, the Swedish and Soviet Governments began negotiating the location of the offshore boundary between the two countries in the Baltic Sea. The talks broke off in April, 1974, without agreement. The point of contention revolves around the island of Gotland. Sweden wants the boundary to lie halfway between Gotland and the Soviet mainland, while the Soviets want the boundary to be drawn halfway between the two mainlands.[181]

The U.S. Geological Survey has estimated that the ultimate recoverable resources of oil in Sweden amount to from 0.1 to 1.0 billion barrels and that the ultimate recoverable natural gas resources range from 0.1 to 1.0 trillion cubic feet.[182]

ARCTIC RUSSIA

INTRODUCTION

Due to a huge jump in crude output from Western Siberia, Russia's oil production in 1974 registered its largest increase in the country's history. Final official figures show that the Soviet Union produced 458.8 million metric tons (9,176,000 barrels per day) of crude oil and gas condensate during 1974. The increase of 29.8 million metric tons (596,000 barrels per day) in 1974 exceeds the 572,000 barrels per day rise in 1973 and the 468,000 barrels per day increase in 1972.[183] Oil production for 1975 was reported at a record 491 million metric tons 9.94 million barrels per day).[184] The officially proclaimed target for 1975 was 489.4 million metric tons (9.93 million barrels per day). By the end of last year, Russia had pushed western Siberian crude output to above 3.2 million barrels per day and the area is soon expected to provide more than one-third of a projected ten million barrel per day total Soviet production. By early 1976, Western Siberia is scheduled to be producing more oil than the State of Texas, where output of crude oil and condensate has slipped to about 3.3 million barrels per day.[185]

Also in 1974, the Soviet Union overtook the United States to become the world's major oil producer with an output nine million tons (66 million barrels) larger than the U.S. Western Siberia accounted for about 95 percent of the U.S.S.R. net oil production gain in 1974.

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[181] Gotland Strikes Spark Soviet Interest. The Oil and Gas Journal, January 28, 1975, p. 75.

[182] Frezon, Sherwood E., op. cit., p. 130.

[183] Gardner. Frank J. Soviets Push for Record Oil Growth. The Oil and Gas Journal, March 3, 1975. p. 44.

[184] Soviets Report Record Sim Months Oil Production. The Oil Daily, July 30, 1975.

[185] W. Siberia to Yield Third of Soviet Oil. The Oil and Gas Journal, December 15, 1975, p. 34.

In 1973 the Soviet Union produced 236 billion cubic meters of natural gas (8.331 trillion cubic feet). In 1974 natural gas production was increased to about 261 billion cubic meters (about 9.213 trillion cubic feet), while the stated target for 1975 was for gas production to exceed 285 billion cubic meters (27.6 billion cubic feet per day). The reported gas production for 1975 was 289 billion cubic meters. The gas production in the Soviet Union in 1975 was increased over 1974 by more than one trillion cubic feet for a total of 10.2 trillion cubic feet (about 27.7 billion cubic feet per day), surpassing the target. Western Siberia, where most of the Soviet gas reserves are located, produced almost 1.33 trillion cubic feet in 1975, compared to 872 billion cubic feet in 1974 and 325 billion cubic feet in 1970.[186] The Soviets expect Western Siberia to produce between 4.06 and 5.12 trillion cubic feet of gas by 1980 with an overall Russian target of 14.12 to 15.36 trillion cubic feet.[187]

The Soviet income from oil and gas sales to foreign customers in 1974 reached an all time high. Although oil exports declined for the first time in 26 years, natural gas deliveries more than doubled.[188] It is estimated that Russia's earnings from exports of crude oil, refined products, and natural gas amounted to nearly $7 billion, based on the current, Russian set, exchange rate of $1.43 per ruble.[189]

The amount of income from foreign oil and gas sales was not given in the preliminary Soviet trade summary, however, the value of total Russian energy exports, including coal and electric power, increased to 5.3 billion rubles in 1974, from three billion rubles in 1973. Of the total energy exports, at least 4.8 billion rubles ($6.864 billion) apparently was earned from the sale of oil and natural gas. With the recent doubling of crude prices to other Communist countries, made retroactive to January 1, 1975, and higher natural gas deliveries, Soviet income from oil and gas exports should continue to rise.[190]

The decline in Soviet crude and refined exports to about 116 million metric tons in 1974 from 118.3 million tons in 1973 was more than balanced by a sharp drop in Russian crude and product imports to 5.4 million tons last year, as compared to 14.7 million tons the year before. Thus, net Soviet oil exports in 1974 were about 110.6 million tons, up from 103.6 million tons in 1973. Product imports may have also been reduced below the 1.5 million tons imported in 1973. Exports of crude oil and refined products to non-Communist countries fell about six million metric tons in 1974, to a total of about 44 million tons; but Communist-bloc nations bought 72 million metric tons of Soviet oil and refined products, up four million tons from 1973. Offsetting the decrease in Russian oil exports, was an increase in natural gas sales from 6.8 billion cubic meters (over 200 billion cubic feet) to 14 billion cubic meters (494.2 billion cubic feet). Soviet gas imports from Iran and Afghanistan in 1974 rose slightly to 12 billion cubic meters (423.6 billion cubic feet) from a 1973 figure of 11.4 billion (over 402.4 billion cubic feet).[191]

Non-Communist European countries bought 39 percent of all exported Russian gas in 1974, while developed capitalist nations throughout the world purchased 67 percent of Russia's refined products exports and 20 percent of its crude oil exports.[192]

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[186] Soviets Claim Gas-production Gain of Over 1 Trillion Cubic Feet. The Oil and Gas Journal, February 23, 1976, p. 68.

[187] Ibid.

[188] Soviet's Foreign Oil, Gas Sales Hit $7 Billion, The Oil and Gas Journal, April 28, 1975, p. 34.

[189] Ibid.

[190] Ibid.

[191] Ibid.

The Soviet Union took advantage of high world prices and shipped a record volume of crude oil to the West in 1975, while holding down the growth of both domestic consumption and exports to its Eastern European allies.[193] Shipments to non-Communist countries rose five times as much as exports to allies, although about three-fourths of Soviet crude oil exports continue to go to Communist countries. The amount of crude oil going to the West increased by 40 percent over 1974 (from 340 million barrels per day to 480 million barrels per day) while exports to Communist nations increased eight percent (to 1.6 billion barrels per day). The Eastern Europeans still pay a preferential price for Soviet oil, somewhat below the world price level.

The high rate of overall exports was made possible by the continuing rise in Soviet oil production and by a reduced growth in the domestic use of petroleum products. Domestic petroleum consumption in 1975 rose five percent compared to annual rates of seven to eight percent in previous years.[194] This trend is a result of the new Soviet energy policy that stresses greater use of coal and other low-grade fuels in power stations and the conservation of oil and gas for use in petrochemicals and for export. However, despite the increased earnings from oil exports to the West, the Soviets were not able to balance the growing costs of their imports of technology and grain.[195]

Most major oil and gas producing regions in the European U.S.S.R. have reached a stage in which output is decreasing at a rapid rate. The growth in Soviet hydrocarbon production since the mid 1960's has been due to the development of new deposits located in remote regions with difficult climatic and geographic conditions. There are nine basins in the Soviet Arctic which have petroleum potential. Three of these basins are known to contain very large reserves of oil and gas; a fourth has been tested and is unproductive to date; and the remaining five basins are mainly untested, though four of these are considered to have excellent petroleum prospects.[196]

Terrain conditions in the Soviet Arctic are very difficult. Permafrost (permanently frozen ground) is extensive and deep in the onshore portions of the West Siberian, the Pechora, and the Vilyuy basins. The permafrost is often over 1,500 meters deep near the coast of the Arctic Ocean, decreasing southward to near zero at 60 degrees north latitude. The deep permafrost layer hinders the development of shallow oil fields and of many of the shallow gas fields of the West Siberian Basin. Methods of producing from the huge shallow gas reservoirs which occur within the permafrost zone of the West Siberian Basin have yet to be developed.[197] permafrost also makes road and railroad construction nearly impossible and has seriously hindered pipeline construction. Temperatures range from 70 below zero in winter to plus 90 degrees (Fahrenheit) in August. The operation of equipment is very difficult in winter because of the cold and in the summer because of wide-spread flooding and the melting of the upper several feet of the permafrost, forming swamps.[198]

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[192] Ibid.

[193] Shabad, Theodore, Russians Step Up Exports to West. The New York Times, May 24, 1976.

[194] Ibid.

[195] Ibid.

[196] Meyerhoff, A. A. Soviet Arctic Oil and Gas: A Second Middle East. Professional Engineer, v. 45, July 1975, p. 29.

[197] Ibid.

Siberia comprises three distinct geographic and economic regions; Western Siberia, Eastern Siberia, and the Soviet Far East. Administratively, they are all a part of Russia (the RSFSR) which is the largest republic in the Soviet Union.[199] The total Siberian population of about 21 million is about 90 percent Russian and Ukrainian and is concentrated in the more southern areas. The Siberian tribes, once hunters and reindeer herdsmen, now lead a more settled life. Western Siberia, with 2.6 million square kilometers (one million square miles) and 10 million people contains the basin of the Ob, Asia's longest river. It is a lowland of forest and marsh, rising gradually in the south to a grassy steppe and to the Altai plateau. Eastern Siberia, with 7.5 million square kilometers (2.9 million square miles) and only 6.5 million inhabitants, is an upland with high mountains in the south. The Soviet Far East, an area of 3.2 million square kilometers (1.2 million square miles) and five million people, has a long mountainous coast with industry and agriculture concentrated in the south.[200]

WEST SIBERIAN BASIN OIL

The first commercial discovery of petroleum in the West Siberian Basin was made in 1953. However, large scale exploration and development did not get underway until 1962, with significant production beginning in 1969 after the first large pipelines were completed. The characteristics of the West Siberian Basin as described in Soviet geological literature are as follows: it is the world's largest sedimentary basin; it contains an oil generating area of 250,000 square miles (about 650,000 square kilometers), equal in size to the State of Texas; it is a relatively simple intracratonic basin with a minimum of structural complexity; the Jurassic and Cretaceous clastics contain excellent reservoir and source rocks (see geologic time scale, Figure 1); the oil is generated in source rocks normally at depths greater than 7,000 feet (about 2,100 meters) which have an average thickness of about 1,700 feet (about 500 meters); the volume of the oil generating rocks amounts to about 80,000 cubic miles (335,000 cubic kilometers) and is calculated to have a generating potential of about 24 trillion barrels of oil.[201]

Of the 1,077 known geologic structures in the West Siberian Basin which are prospective for either oil or natural gas (or both), 250 have been drilled. Of these, only 11 were found dry, hydrocarbons being present in 239.[202] The oil and gas is found primarily in anticlinal structures which are discovered mainly by magnetic, gravity, and seismic profiling.

Many large and giant oil and natural gas fields have been discovered in the West Siberian Basin. Giant oil fields are usually defined as those containing more than 500 million barrels (or 70 million tons) of oil, while giant gas fields are those with more than 3.5 trillion cubic feet (or 100 billion cubic meters) of gas.

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[198] Ibid.

[199] Sanders, Alan, Tapping Siberia's Riches. Far Eastern Economic Review, v. 87, January 31, 1975, p. 58.

[200] Ibid.

[201] McDowell, A. N., What Are the Problems in Estimating the Oil Potential of a Basin. The Oil and Gas Journal, June 9. 1975, p. 89.

[202] Meyerhoff, A. A., op. cit., p. 29–30.

The giant Samotlor on the central Ob River (see map Figure 11), by far the largest Western Siberian oil field, produced its 200 millionth metric ton (1.46 billionth barrel) of crude oil in late November 1975. Soviet officials originally estimated Samotlor's reserves to be two billion metric tons (14.6 billion barrels), but have recently raised the figure to "several billion metric tons".[203] If the original figure is correct, more than ten percent of the estimated initial reserves have now been produced in a field so remote that some Western observers felt that large scale output would barely be started by the mid-1970's. Samotlor's 1975 production target was an average of 1.73 million barrels of oil per day (nearly as much as all the West Siberian Basin fields produced together in 1973) compared with an average of 1.224 million barrels per day in 1974. Output, however, was over 1.8 million barrels per day in late October 1975 and the 1976 average may exceed 2.2 million barrels per day.[204] No other Soviet oil field has ever come near to that output figure. Samotlor is expected to peak at about 2.4 million barrels per day in either 1977 or 1978. There are about 1,000 producing wells in the field which average between 1,700 and 1,800 barrels per day each.[205]

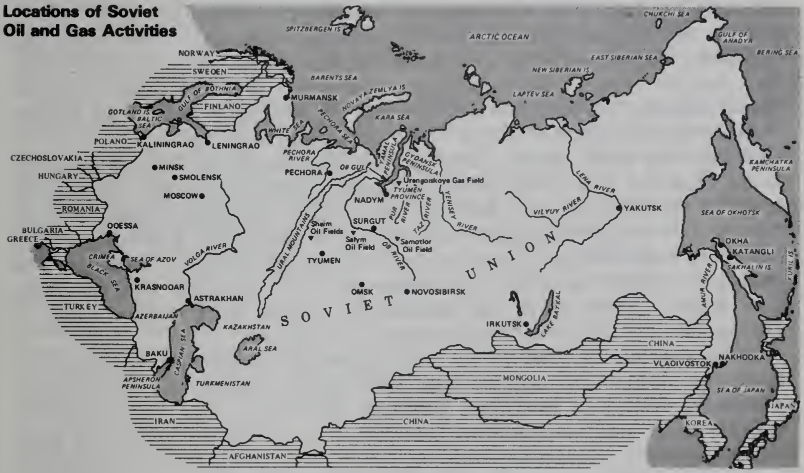
Locations of Soviet Oil and Gas Activities

FIGURE 11

Most of the Western Siberian "explored" oil reserves are in the Nizhnevartovsk district wihch includes Samotlor, Sovetsko, Sosin, Medvedev, Varyegan, Agan, and Pokachev fields.[206] General locations of Soviet oil and gas districts are shown on the map of the Soviet Union. The Nizhnevartovsk district is believed capable of producing 3.2 million barrels per day with an average well output at more than 730 barrels per day.[207] About 190 kilometers (120 miles) down the Ob

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[203] W. Siberia to Yield Third of Soviet Oil, op. cit., p. 34.
[204] Ibid.
[205] Ibid.
[206] Gardner, Frank J., op cit., p. 46.
[207] Ibid.

River, west of the town of Nizhnevartovsky, the Surgut oil district is located. It has a rated maximum production of 1.32 million barrels per day, but the average well output is only about 410 barrels per day, and production costs are higher than in the Nizhnevartovsk district. Important Surgut district fields include Ust-Balyk, Pravdinsk, Mamontovo, and Fedorov. These fields were brought into production between 1964 and 1973. A new giant field, Salym, now is believed to be larger than any of the other Surgut district fields and may contain at least as much oil as Samotlor. The Shaim fields, discovered in 1960 and the first fields to be found in Western Siberia, are located near the Ural Mountains nearly 560 kilometers (350 miles) west of Surgut. These fields have only a small fraction of the reserves occurring in the Nizhnevartovsk or in the Surgut districts. The largest Shaim field, Teterevo-Mortymin, is believed capable of producing no more than 80,000 barrels per day. Trekhozernoye, the second ranked Shaim field in size, has an estimated peak output of 30,000 barrels per day. It is believed that the Soviets will limit total Shaim region output to under 150,000 barrels per day to keep the fields in production for another ten to fifteen years.

The Soviets have recently reported a rare oil field discovery in the northern sector of Tyumen Province, Western Siberia. The strike has encouraged Soviet geologists who still believe that large amounts of oil will be found in this remote northern permafrost area, where almost all major hydrocarbon discoveries thus far have been gas deposits. The discovery was made in the Tarko-Sale district near the Arctic Circle. The discovery well at the new field, named Tarasovskoye, flowed 630 barrels of oil per day from the Lower Cretaceous at a depth of about 8,200 feet (2,460 meters).[208]

While not precisely pinpointed, the Tarasovskoye field is believed to be near the Pur River south of the Urengoiskoye gas field, which may be the largest gas field in the world. Western Siberia's huge middle-Ob oil producing district is located nearly 480 kilometers (300 miles) to the south and southwest of the Tarasovskoye discovery. The only other significant Western Siberian crude oil find near or above the Arctic Circle is in the Russkoye oil-gas field located east of Urengoiskoye. The field was discovered in 1968.[209]

Tarasovskoye is considered by a growing number of Western Siberian geologists to indicate that if large accumulations of crude oil are to be found in northern Tyumen Province, they will be in the smaller structural depressions between the area's giant gas filled anticlines. Small amounts of crude oil have been found beneath the main gas zones of the giant gas fields (Urengoiskoye, Gubkinskoye, Medvezhye, Zapolyarnoye and Tazovskoye), but in quantities which are quite small in comparison with the gas. It is now considered advisable to drill deep wells beyond the giant gas fields to search for crude oil in stratigraphic traps in the structural depressions.[210]

Soviet plans call for developing Western Siberia's larger oil fields first, followed by medium sized fields and smaller fields in that order. Within each category, priority will be given to fields with high yield wells averaging over 80 metric tons of oil per day (584 barrels of oil per day), followed by fields with wells averaging 40 to 80 metric tons per day (292 to 584 barrels of oil per day), and finally fields with wells averaging less than 40 metric tons (292 barrels per day).[211]

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[208] Rare Strike in Siberia is Reported. The Oil and Gas Journal, September 15, 1975, p. 242.

[209] Ibid.

[210] Ibid., p. 243.

Until last year, none of the more than two hundred oil fields discovered in Western Siberia was believed to have even one-fifth of Samotlor's reported 15.1 billion barrels of initial reserves. The next largest field was Ust-Balyk, with estimated reserves of 2.85 billion barrels. Late in 1974, however, the Soviets reported that step-out drilling at Salym field, located about 240 kilometers west of Samotlor, in the Surgut district indicated reserves which may prove to be even larger that those at Samotlor. Salym is a stratigraphic trap in which the oil occurs in huge Jurassic sand wedges within shales at depths 9,000 to 9,500 feet (about 3,700 to 2,850 meters). The area of the field is reported to be 10,000 square kilometers (3,860 square miles) underlain in some sections by as many as eight oil productive zones.[212]

Total proved oil reserves in the West Siberian Basin are not reported in the Russian literature, but have been variously reported as 87 billion barrels (2½ times the proved reserves of the United States including Alaska) [213] to as much as 100 billion barrels recoverable oil.[214] If as much as 500 billion of oil were contained in these fields, this would represent only two percent of the quantity that could theoretically be generated from the sediments in the West Siberian Basin. As a general statement, it appears that the oil recoverable from a sedimentary basin is no greater than ten percent of the amount generated, but that three percent is a more representative expectation for the average basin.[215]

Other reports, however, question reserves of this magnitude. The *Oil and Gas Journal* list total Russian oil reserves at only 80.4 billion barrels.[216] This figure would allow for total Arctic petroleum reserves about one half as large, around 40 billion barrels. Also, the West Siberian region is known for its harsh climate. Winter brings deep frosts, snow, and violent storms and there is extensive flooding from spring until August, particularly in the Ob River valley. Sixty percent of the West Siberian plain is swamp and the rest is dense coniferous forest. Potential immigrants are discouraged by mosquitoes, floods, and swamps in the summer and the cold and isolation in the winter. Between 1959 and 1969, Soviet sources reported that nearly one million more people left Siberia than went to live there, despite above average wages offered especially in the oil fields.[217] There is also the high cost of infrastructure, roads, pipelines, housing, etc., to be considered in such remote areas with no links to the outside world of consumers and suppliers. These considerations, and even more serious problems of poor organization and badly lagging technology, have caused some observers to conclude that either Siberian oil and gas resources are not as huge as originally claimed or that their development is too complex or prohibitively expensive.[218] Another indication in favor of such an analysis is that the Soviets have stepped up extensive oil and gas exploration in their European and offshore regions at the expense of a more complete concentration of development resources on Siberia.[219]

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[211] Gardner, Frank J., op. cit., p. 46.

[212] Gardner, Frank J., A New Name to Remember. The Oil and Gas Journal, May 26, 1975, p. 35.

[213] Meyerhoff, A. A., op. cit., p. 30.

[214] McDowell, A. N., op. cit., p. 89.

[215] Ibid.

[216] Auldridge, Larry, Worldwide Report. The Oil and Gas Journal, December 29, 1975, p. 87.

[217] Russia, a Buyer of Oil The Economist, July 19, 1975, p. 61.

[218] Slocum, Marianna. Soviet Energy: An Iinternal Assessment. Technology Review, November 1974, p. 22.

In fact, the Soviet Government recently passed a series of new resource conservation laws, to become effective next January 1; which, among other measures, mandated improved geological prospecting. In an introduction to the laws by a deputy premier, Soviet geologists were harshly criticized for certain cases of inadequate confirmation of reserves of minerals which caused changes in projects, increased expenditures, and other negative consequences. The deputy added that poor quality geological prospecting and general mistakes and errors in the estimates of reserves lead to wasted funds; and, that the new laws would assure more effectiveness and trustworthiness in prospecting and in assessing the quantity and quality of reserves.[220]

However, Western geologists who have visited and studied the West Siberian Basin indicate that, while the basin itself perhaps cannot yet be considered another Persian Gulf, its petroleum potential is very great. Any conservative estimate of the expected ultimate oil production in the basin should take into account such factors as a relatively shallow basement and hydrocarbon pay zones which are generally ten meters or less in thickness.[221]

The entire sedimentary section has been tested in the oil producing area. Facies changes are present in the basin and the producing formations may be too sandy in the south and east and too clayey in the north and west.[222] However, the ultimate oil recovery, even which such somewhat negative factors are taken into consideration, is considered to be greater than 73 billion barrels (10 billion tons) and probably several times that.[223]

Poor Soviet drilling and production technology have caused serious problems in Arctic development. Drilling rigs are turbodrills rather than rotary rigs as are used in the West. Turbodrills are inefficient, breaking down rapidly below 7,600 (2,280 meters) feet. Drilling steel is scarce and of low quality, mostly non-carbon steel is used. Drill bits are poorly constructed and inefficient. It sometimes takes 13 months to drill 10,000 feet (3,000 meters) in the Soviet Union as contrasted to an average of 34 days in the United States. A 16,000 foot well (4,800 meters) may take three to five years to drill, while in the United States such wells are commonly drilled in a few months.[224] Scientific, economic drilling muds have not been developed and well testing equipment is poor in the U.S.S.R. Separate wells must be drilled to each reservoir in a field, whereas in the West completions from several reservoirs are commonly made in the same well. Blowout preventers are a rarity in the Soviet Union. Pipeline equipment is scarce and pipe leakages are very common as pipe joints are of poor quality. Refineries are inadequate to produce more than a few products. Compressor and mud pumping units are underpowered and of poor quality.[225] Exploitation will be continued at an increasingly rapid rate, but outmoded equipment is expected to cause a sharp decline in future exploration and discovery efficiency. Russia lacks sophisticated geophysical tools, such as modern seismic equipment and computerized field exploration units. To offset the equipment and technological problems, the Soviet Union will probably have to import large quantities of modern Western equipment and technology which will require the development of closer commercial ties with the United States, Western Europe, and Japan.[226]

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[219] Ibid.

[220] New Russian Laws Stress Mineral Conservation. Engineering and Mining Journal. August 1975, p. 143.

[221] Dickey, Parke A. Geology of Oil Fields of West Siberian Lowland. The American Association of Petroleum Geologists Bulletin, v. 56, n. 3, March 1972, p. 471.

[222] Ibid.

[223] Ibid.

[224] Meyerhoff, A. A., op. cit., p. 31.

[225] Ibid.

Development of West Siberian fields such as Samotlor, much of which is under a large lake, is done by slant cluster drilling. The concentration of many well heads at one point has the advantage of reducing the required length of a field's roads, pipelines, and power and communication lines. The rig can be moved intact from one directional drilling point to another on the cluster platform without having to be dismantled and then rigged up. Over one hundred cluster drilling platforms have been constructed in the West Siberian area and some holes have been deviated by as much as 7,000 feet (2,100 meters). The oil zones at Samotlor are comparatively shallow, usually ranging from 6.500 to 8,000 feet or less. (1.950 to 2,400 meters).[227]

The Soviet Union has started test production of an extremely viscous crude oil from the large Russkoye field in the Western Siberian Basin above the Arctic Circle near the Taz River. About 1,500 barrels of oil was extracted from an Upper Cretaceous zone at a depth of 2,625 feet (788 meters), just below the permafrost layer. The viscosity of the Russkoye oil is reported to be 200 times higher than that of the crudes found in Western Siberia's main producing areas about 640 kilometers to the southwest along the Ob River.[228]

The Soviets have also recently announced the development of a thermal mining method to produce high-viscosity crude oil which is not recoverable by conventional means. The method has been in use since 1972 in the Yarega oil field near Ukhta, Komi Autonomous Soviet Socialist Republic, located about 1,200 kilometers northeast of Moscow. Soviet petroleum engineers hope to recover from 50 to 60 percent of the original in-place oil in the Yarega field, where conventional development with surface pumps would be expected to yield only two percent. The thermal mining method is being offered for license to the United States where, according to the Soviets, many suitable locations for this sort of technology exist.[229]

At present, however, waterflooding is the basic oil recovery method in the Soviet Union. It is applied in more than 220 fields where production amounts to 81 percent of the total oil production of the country. The volume of water injected into Soviet fields exceeds 800 million cubic meters per year.[230] In fields where waterflooding has been used, ultimate recovery is reported to exceed 50 percent of the in-place oil compared to 18 to 35 percent recovery from fields produced with only a natural drive. Russia's oil production has increased 15 times during the period since waterflooding has been developed. In 1974 oil production totaled about 458 million metric tons, more than 240 million tons of which was due to waterflooding, according to Russia's Minister of Oil.[231] Studies conducted by the U.S.S. R. indicate that the cost of waterflooding at the beginning of development is from 30 and 40 percent higher than development costs without initial waterflooding. However, the waterflooding permits higher reservoir pressures and production rates which allow an eventual higher recovery factor, making the added expenses economic. According to the Soviets, a new field is first drilled on a wide spacing pattern in the range of 240 to 320 acres per well (compared to 10 to 12 acres in Western practice). This allows the fields to be studied and their basic overall geological characteristics to be determined. Then a narrowing of well spacing is carried out by drilling "reserve" wells in the necessary areas. When the fields are finally put into production, the average well spacing is not less than 120 to 160 acres per well. The Russians claim that such wide spacing in combination with waterflooding results in a high rate of production and recovery. Block waterflooding is the most widely applied technique. It is used in most of the fields of Western Siberia. In block flooding, the pools are divided into oil producing blocks surrounded by water injection wells. Currently, some of Russia's fields are producing at a rate of eight to ten percent of reserves per year. The Soviet's feel that with increase in injection pressure, productivity is increased and injection wellhead pressures reach 150 to 200 atmospheres while bottom hole pressures are near rock pressure.[232]

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[226] Ibid.

[227] Bakke, Donald R., Russian "Cluster Drilling" Allows Multi-well Development in Siberia. Offshore. March 1973. p. 35.

[228] Soviets Test-produce Heavy Oil. The Oil and Gas Journal. April 28, 1975. p. 47.

[229] Mining of Viscous Crude Claimed Viable. The Oil and Gas Jounal, January 5, 1976, p. 46.

[230] Russians Start Waterflooding to Hike Production. The Oil and Gas Journal, May 26, 1975, p. 80.

However, to meet production quotas and to receive bonuses for exceeding quotas, wells are sometimes overproduced and water is injected at harmfully high rates and pressures.[233] Commonly, the water is injected before the physical properties of the reservoir or of the oil have been determined. In some fields overproduction and excessive pressures have resulted in great amounts of water coning and bypassing of primary recoverable oil.[234] In certain fields the bypassed oil has been estimated to be in the hundreds of millions of barrels. Waterflooding is not always a proper method of secondary recovery. One Soviet field was almost totally destroyed by the waterflooding of oil consisting of 22 to 28 percent parafin. The parafin base oil congealed, locking most of the oil in the reservoir.[235]

Russia no longer has the pipeline bottleneck that it had in the early 1970's between the main West Siberian fields along the middle course of the Ob River and the refining centers. A 40-inch and two 48-inch crude oil lines have been completed. One of the 48-inch links runs 1,830 kilometers southwest across the Ural Mountains and terminates at Almetyevsk in Tataria. The other, finished as far as Kransnoyarsk, is being extended eastward to the big Angarsk refinery near Irkutsk. At Anzhero-Sudzhensk this new pipeline connects with the trans-Siberian railroad and with an old small diameter pipeline running eastward to Irkutsk.

A new 48-inch pipeline is being laid parallel to the existing 48-inch artery that crosses the Urals and will terminate at Kuibyshev on the Volga. Here it will connect with pipelines feeding Black Sea oil-loading ports and Eastern European counties including Poland, Czechoslovakia, East Germany, and Hungary.[236] A short new large diameter link is being built at the nothern end of the pipeline running from the middle Ob River area southeast toward Irkutsk. It will allow the delivery of additional Samotlor crude to the Angarsk refinery and to other refineries in the Soviet far east. A total of at least 1,500 barrels per day of additional pipeline should be available to transport crude from middle Ob fields by the end of 1976.[237]

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[231] Ibid.

[232] Ibid. p. 82.

[233] Meyerhoff, A. A. Geopolitical Implications of Russian and Chinese Petroleum. Exploration and Economics of the Petroleum Industry, New Ideas, New Methods, New Developments, v. II, 1973, p. 119.

[234] Ibid. p. 121.

[235] Ibid. p. 122.

Russia appears to be following a detailed long range plan for developing its Western Siberian fields, making changes to meet new conditions such as Salym's expanded potential. The most productive fields closest to the Ob River, existing pipelines, the new railroad between the cities of Tyumen and Surgut, and the small network of hard surfaced roads are being developed first. As a result, Western Siberian crude now being produced requires considerably less investment per barrel of output than the oil that will come from fields slated for development in the 1976 to 1980 period and later.[238]

Beyond 1980, the Soviets believe that most of Western Siberia's undiscovered oil reserves will be found farther north in the Arctic regions that are now essentially gas provinces containing several of the world's largest gas fields. This area has no oil pipelines, railroads, hard surfaced roads, or even a large navigable river comparable to the Ob. The oil and condensates are believed to lie at considerably greater depth than the gas, thus drilling costs will be higher along with the transportation costs. Elsewhere in Western Siberia the small fields will have to be developed in the 1980's also at greatly increased expense per barrel of output.[239]

WEST SIBERIAN BASIN GAS

Russia is acquiring the gas production capability to overtake the United States and become the world's largest gas producer, perhaps during the 1980's. Long hampered by poor planning and inferior technology, the Soviet gas industry still produces less than half as much gas as the United States.[240] In 1960 Russia produced about 12 percent as much gas as the United States, in 1970 nearly 32 percent, and 41 percent in 1974. In 1975, the Soviet Union produced 10.2 trillion cubic feet of gas (285.6 billion cubic meters), compared to 9.2 trillion cubic feet (157.6 billion cubic meters) produced in 1974. Soviet "explored" (proved plus probable) gas reserves exceed 882.5 trillion cubic feet (24.7 trillion cubic meters), a volume that would sustain 1974 production for over 95 years.[241] In addition to these huge proved plus probable reserves, by far the world's largest the Soviets claim to have over 700 trillion cubic feet (19.6 million cubic meters) of possible gas reserves in "promising" gas producing areas.

The largest volume of Russia's known gas reserves is located in the northern part of the Western Siberian Basin. This vast area is considered to contain gas reserves in the range of from 507 [242] to 787 [243] trillion cubic feet (14.2 trillion cubic meters to 22.0 trillion cubic meters).

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[236] Gardner, Frank, J. Soviets Push for Record Oil Growth, op. cit., p. 47.
[237] Ibid.
[238] Ibid. p. 47X48.
[239] Ibid. p. 48.
[240] Gardner, Frank J. Russia Aiming to Surpass U.S. in Production of Gas. The Oil and Gas Journal, April 14, 1975, p. 21.
[241] Ibid. p. 22.
[242] Ibid.
[243] Meyerhoff, A. A. Soviet Arctic Oil and Gas: A Second Middle East, op. cit., p. 30.

Western Siberia produced almost 1.33 trillion cubic feet of gas in 1975 compared with 872 billion cubic feet in 1974 and 325 billion cubic feet in 1970. Commercial production of gas began in Western Siberia in 1966. The Soviets expect that Western Siberia will produce between 4.06 and 5.12 trillion cubic feet of natural gas in 1980, while the overall 1980 Soviet gas production target is 14.12 to 15.36 trillion cubic feet.[244]

The largest gas field in the world, Urengoiskoye, located east of the boom town of Nadym, may have ultimate reserves considerably larger than all current proved gas reserves in the United States, according to Soviet geologists. Explored Urengoiskoye reserves in upper pay zones are estimated at 176.5 trillion cubic feet, compared with 30 trillion cubic feet at Prudhoe Bay, Alaska. It is believed that an additional 105.9 cubic feet of possible gas reserves exist in the lower horizons of Urengoiskoye.[245] Other giant Western Siberian gas fields include: Yamburgskoye (70.6 trillion cubic feet of explored reserves) on the Taz Peninsula north Urengoiskoye; Medvezhye (60 trillion cubic feet of initial reserves) between Nadym and Urengoiskoye; and Zapolyarnoye (57.2 trillion cubic feet of explored reserves) northeast of Urengoiskoye.[246] Altogether, about 70 gas fields have been discovered in Western Siberia since the first commercial discovery near Berezovo, west of the Ob River, in 1953. During the next ten years 22 other small fields were found, the largest being Punginskoye Punga and Yuzhno-Igrimskoye with combined explored reserves of about seven trillion cubic feet. The first large Western Siberian field, Tazovskoye, was discovered above the Arctic Circle in 1962. Other large fields found soon after Tazovskoye were: Gubkinskoye and Zapolyarnoye in 1965; Komsomolskoye and Urengoiskoye in 1966; Medvezhye in 1967; Arkticheskoye, Russkoye, and Vengapurskoye in 1968; and Yamburgksoye, Yubileinoye and Yuzhno-Russkoye in 1969.[247]

Pestsovoye, a gas field found in March 1974, has also been officially placed in the "giant" category. The Soviets estimate that it has reserves of 10.6 trillion cubic feet (300 billion cubic meters) of gas and also 50 million metric tons of gas condensate.[248] The Pestsovoye field is located just above the Arctic Circle, a short distance northwest of Urengoiskoye.

These major far northern Western Siberian Tyumen Province fields yield, according to Soviet sources, gas with methane contents up to 98 or 99 percent. While fewer giant gas fields have been discovered in the 1970's than in the 1960's, the Soviets are confident that reserves will continue to increase rapidly. As an example, one wildcat recently drilled on the Taz Peninsula, above the Arctic Circle, increased that district's explored reserves by more than 116 trillion cubic feet. Also, most of the over 1,000 structures already discovered in Western Siberia are still unexplored or only lightly explored and some Soviet geologists believe that at least 3,000 such structures eventually will be found in Western Siberia. Thus far, almost all of Western Siberia's gas has been found in Mesozoic structures at depths of 2,297 to 8,858 feet (669 to 2,657 meters). The average depth of the regions gas zones is only 5,249 feet (1,575 meters).[249]

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[244] Soviets Claim Gas-production Gain of Over 1 Trillion Cubic Feet. The Oil and Gas Journal, February 23, 1976, p. 68.

[245] Gardner, Frank J. Russia Aiming to Surpass U.S. in Production of Gas. op. cit., p. 22.

[246] Ibid.

[247] Ibid.

[248] Soviets Tag Gas Field as New Giant in Siberian Arctic. The Oil and Gas Journal, June 9, 1975, p. 17.

The West Siberian Basin continues northward beneath the Yamal Peninsula and the Kara Sea. In the Kara Sea the thickness of the sedimentary section is believed to be two or three kilometers, but a considerable increase in the sandstone section is expected along with possible large gas and gas condensate accumulations occurring in vast uplifted structures at shallow depths.[250] Russia has announced plans to explore the offshore sector of the giant Kharasavei gas field which was discovered in May 1974, on the Kara Sea coast of the Yamal Peninsula. Kharasavei reserves, discovered below 5,250 feet (1,575 meters), are estimated to be about 35.3 trillion cubic feet (almost 1 trillion cubic meters).[251] The Soviet are convinced that the Kharasavei structure extends beneath the Kara Sea and there are indications that preparations will soon be made for offshore drilling. The Kara Sea is ice choked for about nine months of the year and very foggy. However, its waters are comparatively shallow, averaging less than 400 feet (120 meters) in depth. Promising potentially petroliferous structures occur beneath the Kara Sea and in the Ob River Gulf which extends along the eastern coast of the Yamal Peninsula. It has been estimated by Soviet geologists that the Kara Sea contains 388 trillion cubic feet of gas reserves, more than 48 percent of the total estimated potential gas reserves for all offshore areas of the Soviet Union.[252]

There have been eight gas fields found on the Yamal Peninsula including the first field, Novoportovskoye, discovered in 1964. The Soviets now believe that a chain of gas fields stretches east to west across the entire Yamal Peninsula from the Ob Gulf to the Kara Sea. The two gas fields to be discovered on the Peninsula most recently are the Yuzhno-Tambeiskoye and the Malo-Yamalskoye.

The Soviets believe that commercial gas deposits will also be found in southwestern Siberia's deeper and more poorly explored Paleozoic formations. Several Paleozoic oil finds have been made in Siberian areas.

In 1975, the Medvezhye field, over 129 kilometers (80 miles) long and 56 kilometers (35 miles) wide, was the only giant Western Siberian gas field in production. Its 1974 output of 671 billion cubic feet from about 40 development wells amounted to 77 percent of the total 1974 Western Siberian gas production. In 1975 Medvezhye produced 1.6 trillion cubic feet of gas, about 90 percent of Western Siberia's output. The development wells are reported to be equipped to handle gas flows of up to 176.6 million cubic feet per day. In actual practice, however, these wells at Medvezhye apparently yield a maximum of 70.6 million cubic feet of gas per day.[253] According to Russia's Ministry of the Gas Industry, modern control systems and automated methods for all technological processes used in the extraction and treatment of gas are employed at the Medvezhye field. Large diameter development wells and extensive automation also will be utilized at Urengoiskoye (slated to begin gas production in 1977 at about 1.06 trillion cubic feet per year) and the other giant gas fields in northern Tyumen Province. Because of the extreme difficulty in moving rigs across the swamps of Western Siberia, wells are grouped together whenever possible. At Urengoiskoye, 150 high output wells are planned to provide the same total production as 600 "conventional" wells. The high yield wells will be drilled in clusters of four development wells with one or two "reserve" wells and one observation well.[254] Urengoiskoye gas collection points will each be designed to handle about 1.13 billion cubic feet per day from 32 wells each producing an average of 35.3 million cubic feet per day.

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[249] Gardner, Frank J., Russia Aiming to Surpass U.S. in Production of Gas, op. cit., p. 2.

[250] Eremenko, N. A., Ovanesov, G. P., and Semenovich, V. V., Status of Oil and Gas Prospecting in the U.S.S.R. in 1971, The American Association of Petroleum Geologists Bulletin, v. 56, n. 9, September 1972, p. 1716.

[251] Russia Will Explore Gas Field North of the Arctic Circle. Offshore, December, 1974, p. 122.

[252] Ibid.

[253] Ibid.

A gas treatment facility will be connected to eight clusters of wells (32 wells). At Medvezhye the gas producing zone, the Cenomanian (Cretaceous) is between 3,468 and 3,960 feet (1,040 to 1,188 meters) below the surface. Deeper holes (to over 16,000 feet or 4,800 meters) are underway at the Medvezhye field in an effort to find new gas horizons and possible gas condensate or crude oil. If hydrocarbons are present below the Cenomanian at Medvezhye, it is possible that this could also be the case at Urengoiskoye since the geology of the two fields is very similar.

Gas from Medvezhye is transported to Moscow by a 48-inch pipeline completed in the fall of 1974. Deliveries across the Urals will increase as more large diameter pipelines are constructed and more giant gas fields near and above the Arctic Circle are put into production. The Soviets have encountered considerable difficulty with their first short small diameter gas pipelines built on supports over permafrost near or north of the Arctic Circle. There have been frequent breaks, caused by high winds and huge temperature variations.

Hydrate plugs have greatly reduced the reliability of two above ground pipelines connecting gas fields near the mouth of the Yenisei River with the mining center of Norilsk in North Central Siberia. These links, constructed in 1969, traverse about 240 kilometers (150 miles) of permafrost almost 320 kilometers (200 miles) north of the Arctic Circle. Experience with above ground pipelines in Arctic areas apparently has convinced the Soviets that pipelines from their giant Western Siberian fields should be brought south below the permafrost latitude as directly as possible and should be buried underground whenever practicable.[255] Also, pipeline engineers appear to favor a maximum pipeline diameter of 56 inches (142.24 centimeters), with the introduction of a 64 inch (162.56 centimeters) pipe coming in the next few years. Rather than moving quickly to pipelines as large as 100 inches (254 centimeters), the Soviets are placing greater emphasis on increasing operating pressure of 40-inch, 48-inch, and 56-inch lines from 808 pounds per square inch to 1,102 pounds per square inch and eventually to 1,470 pounds per square inch and more.[256] The Soviets claim that increasing gas pipeline pressure from 808 pounds per square inch to 1,102 pounds per square inch increases throughput capacity by 30 to 40 percent while reducing metal consumption by 10 to 15 percent. Studies of Soviet pipeline operations also shows that the use of two or more parallel smaller diameter pipelines with combined capacity equal to one larger diameter pipeline provides greater transmission reliability considering the frequency of operational disruptions in the remote Arctic areas of the Soviet Union.

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[254] Ibid.
[255] Ibid. p. 24.
[256] Ibid.

In Western Siberia, a 56-inch gas pipeline links the giant Medvezhye field with the town of Nadym, about 100 kilometers (62 miles) to the west. From Nadym, two 48-inch pipelines transmit gas to industrial centers of the Ural area and also across the mountains to Moscow. A third link from Nadym through Punga to Nizhnyaya Tura, on the eastern slope of the Urals, is almost completed. The most northerly of the two trans-Ural gas pipelines extends west from Punga across the mountains to the large Vuktylskoye field in the Komi Autonomous Republic and on to the city of Ukhta where it connects with the 48-inch "Northern Lights" system. The Northern Lights originally carried Vuktylskoye gas only as far as Torzhok (between Moscow and Leningrad but a 640 kilometer 38-inch southwestward extension to Smolensk and Minsk has recently been completed and the Northern Lights is shortly expected to reach Ivatsevichi, about 88 kilometers from the Polish border and about 4,000 kilometers from Medvezhye. A second gas line from Punga to Ukhta through Vuktylskoye is also near completion. The first three pipelines fed by the Medvezhye and Urengoiskoye fields will have a rated capacity of 1.6 to 2.1 trillion cubic feet of gas per year, but usable capacity will be much lower because of the Russian practice of activating pipelines long before all of the compressor stations are completed.

PECHORA BASIN

The Pechora Basin is located west of the Ural Mountains in the European part of the U.S.S.R. The total area of the basin is 300,000 square miles (780,000 square kilometers), 60,000 square miles (156,000 square kilometers) onshore and 240,000 square miles (624,000 square kilometers) beneath the Barents Sea. The operational problems present in the West Siberian Basin are also present here. Hydrocarbon exploration of the region was begun in the 1920's with the first discovery at Ukhta in 1929. Currently, the exploration rate appears to be lagging behind scheduled plans, due to a lack of equipment. Most available equipment is being utilized in the West Siberian Basin.[257]

In the Pechora Basin, the basement rocks are overlain by a thick sedimentary cover including almost the entire Paleozoic sequence and, in the northern part, almost the entire Mesozoic sequence also. Large anticlines separated by broad depressions occur within the basin. Commercial oil and gas reservoirs are found in Silurian, Middle and Upper Devonian, Lower and Middle Carboniferous, and in Permian aged rocks. More than 45 oil and gas fields have been discovered in the Perchora Basin.[258] Two gas fields, Vuktyl and Layavozh, contain 35 trillion cubic feet of gas, an amount equal to 15 percent of the proved gas reserves of the United States. Several hundred potentially productive structures, most of them offshore beneath the Barents Sea, remain to be tested.[259]

The Vuktyl field is composed of a narrow fold 75 by five kilometers in size. The main gas reserves are in Middle Carboniferous limestone and dolomite, but the underlying Devonian sediments also are prospective.[260] In the northern part of the area, the large Layavozh and Vasillcovskoye gas fields, discovered in 1971, produce from Lower Permian limestone. Stratigraphically deeper Carboniferous. Devonian, and Silurian aged oil and gas reserves are expected eventually to be found in these structures.

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[257] Meyerhoff, A. A. Soviet Arctic Oil and Gas: A Second Middle East, op. cit., p. 30.
[258] Ibid.
[259] Ibid.

A new oil and gas find has been recently made at Varandei near the southeastern end of the Pechora Sea where undisclosed quantities of oil and gas were recovered from about 5,500 feet (1,650 meters). The area, more than 150 miles (240 kilometers) north of the Arctic Circle, lies at the northern end of the remote Bolshezemelskaya Tundra. The Varandei structure is believed to extend offshore, thus causing Soviet geologists to speculate on the possible existence of hydrocarbons along a large area of the Barents Sea shelf. The Soviets have completed extensive seismic surveys in the Barents Sea and have estimated the oil and gas potential for the offshore area.

Proved Pechora oil reserves are 1.5 billion barrels and proved gas reserves are 45 trillion cubic feet.[261] The ultimate potential of the Pechora Basin, onshore and offshore, is considered to be at least 50 billion barrels of oil and 500 trillion cubic feet of gas (14 trillion cubic meters).[262]

EAST SIBERIAN PROVINCE

The East Siberian Province or Siberian Platform covers a vast territory of more than three million square kilometers between the Yenisey and the Lena Rivers.

Potential oil and gas bearing regions occur where downwarps with sedimentary covers are present. The main Arctic basin in the East Siberian Platform is the Vilyuy Basin, located about 2,100 kilometers east of the West Siberian Basin. The Vilyuy Basin includes about 100,000 square kilometers of territory. The deeper structures are complex and involve mainly Precambrian and Paleozoic rocks. A Devonian salt dome province occurs in the western portion of the basin. The post-Carboniferous (post-Mississippian and Pennsylvanian) rocks range in thickness from 250 meters in the west to about 8,000 meters in the east.[263]

Systematic exploration of the Vilyuy Basin began in the early 1950's and gas was discovered in 1956. Eight gas fields were found with combined proved reserves of about 17 trillion cubic feet.[264] Oil has not as yet been found in commercial quantities. The gas is found in Lower Jurassic, Triassic, and Upper Permain marine, littoral, and deltaic sandstone reservoirs. Two giant fields have been found. The first field discovered, the Ust-Vilyuy, while not a giant, has reserves about one trillion cubic feet and lies at the junction of the Vilyuy and Lena Rivers. A pipeline has been built to Yakutsk and Pokrovsk where the gas is used by local industry. The other gas reserves in the Vilyuy Basin have not been developed because of a lack of a local market. There is a possibility, however, that a pipeline may eventually be constructed to carry Vilyuy gas to Khabarovsk, a large industrial center on the Amur River.

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[260] Eremenko, N. A., Ovanesov. G. P. Semenovich, V. V., op. cit., p. 1713.

[261] Meyerhoff, A. A. Soviet Oil and Gas : A Second Middle East, op. cit., p. 30.

[262] Ibid.

[263] Meyerhoff, A. A., Mamantov, Ilya A., Shabad, Theodore. Russian Arctic Boasts Big Potential. The Oil and Gas Journal, October 25, 1971. p. 125.

[264] Meyerhoff, A. A. Soviet Arctic Oil and Gas : A Second Middle East, op. cit., p. 30.

In August, 1974, the remote Verkhne-Vilyuchanskoye gas field was discovered in Eastern Siberia's Yakut Autonomous Republic. Confirmation drilling in the field has increased gas reserve estimates for the Vilyuy oil and gas province. The Soviets now estimate the potential gas reserves for this area at 452 trillion cubic feet (12.6 trillion cubic meters). Exploration and drilling is being increased in the Vilyuy province and exploration is also being increased in Yakut's other two gas provinces, Lena-Aldan and Anabar.[265] The entire Vilyuy area is within the permafrost zone and is remote and nearly inaccessible by ground except during the winter.

To the North, the Laptev Sea shelf has an area of about 650,000 square kilometers and at the edge of the continental slope its depth is about 100 to 200 meters. The most favorable oil and gas prospects in the region are in the rocks of the Khatanga depression and in the southern Laptev trough, which are similar in structure.

EAST SIBERIAN AND CHUKCHI SEAS

The East Siberian Sea and the Chukchi Sea, off the eastern coast of Siberia, are both quite shallow. The average depth of the East Siberian Sea is only 50 meters while the Chuckchi Sea averages 80 meters in depth. The shelves are characterized by large positive and negative structures. Oil and gas potential is considered to be favorable in the negative basins and depressions. No drilling has as yet been done offshore. The East Siberian Sea and the Chukchi Sea appear to be geologically continuous with the Alaska North Slope. The Soviet Union has the largest continential shelf area of any nation in the world and 92 percent of this shelf is in the Arctic.

ANADYR' BASIN

This Pacific basin of about 60,000 square kilometers includes both onshore and offshore sections overlying a basement of Mesozoic volcanic rocks. Two noncommercial gas discoveries have been made in sandstones of Upper Cretaceous and Lower Tertiary age. No fields have as yet been outlined, but the offshore area shows promise to become a small commercial gas province. If the fields should be developed in this basin, however, transportation will present a problem as the area is far from major population centers.

FUTURE DEVELOPMENT

The Government of the U.S.S.R. is committed to the rapid development and exploitation of the West Siberian Basin, excluding its offshore extension beneath the Kara Sea. Of secondary, but nearly equal, priority is the development and exploitation of the Pechora Basin, excluding its offshore extension beneath the Barents Sea. Third in priority among the Arctic Basins in the Vilyuy Basin.[266]

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[265] Soviets Confirm Gas Field in Eastern Siberia. The Oil and Gas Journal, November 24, 1975, p. 31.

[266] Meyerhoff, A. A. Soviet Arctic Oil and Gas. A Second Middle East, op. cit., p. 31.

The Soviet Union with its vast reserves of oil and natural gas, has overtaken the U.S. as the world's leading petroleum producer. Its mid-1975 production was over 9.7 million barrels of crude per day while the United States production had fallen to 8.4 million barrels per day.[267] The Soviet petroleum industry, however, has had trouble meeting the production goals set in the five year plan for 1971–75. The goal for 1974 called for production of just over 9.2 million barrels daily, but only 9.1 million barrels per day were actually produced. Last year's goal was 9.9 million barrels per day, but it is doubtful that it was reached. There is also a question of the Soviets' ability to reach the preliminary 1980 goal of 12 million barrels of crude per day. However, there have been long range estimates that the Russians will be producing as much as 21 million barrels per day by 1985–90 with some sources forecasting crude production as high as 25 million barrels per day by 1990.[268] Exploitation will probably be continued at an increasingly rapid rate, but outmoded equipment could cause a sharp decline in exploration, discovery, and production efficiency probably during the late 1970's and early 1980's.

There are also signs that the Soviet Union is already having problems in the short run staying even with demand. In 1974, despite the very high price of oil on the world, the Soviet Union cut its exports to the West to 880,000 barrels per day from just over one million barrels per day in 1973. This was done in spite of the fact that Russia depends upon oil sales to earn the hard currency with which to buy Western technology and food. Western technology remains important, if not crucial, to the long range development of Russian oil and gas reserves, particularly those located in the harsh and remote areas of the Arctic. It is estimated that Soviet oil exports to the West in 1980 will be somewhere near the 1.2 million barrels per day, the same as was projected for the mid-1970's.[269]

In the push to develop new fields particularly in the Arctic and offshore, the Soviets concede that Western technology, equipment and capital, would be of considerable assistance. The Congress of the United States, however, has placed stringent restrictions on the U.S. Export-Import Bank's authority to grant loans involving the Soviet Union. The Soviets were interested in obtaining Export-Import Bank credits at generous six or seven percent interest rates and at least five American companies were counting on the credit to obtain Soviet contracts. The Japanese were looking for evidence of solid American backing before taking on some of the projects themselves.[270] In the view of Congress, and a large number of critics of East-West trade and technology transfer, the subsidising of trade with the Soviet Union was unacceptable. Congress set a $75 million annual limit on credits to the Soviet Union was a $40 million sub-limit on loans involving research and exploration of fossil energy in the Soviet Union. However, a company may obtain a larger loan for Soviet fossil fuel development as Congress may vote to authorize a particular project if the President confirms that it is in the national interest. This could, of course, prove a difficult procedure, and it thus appears that Export-Import Bank funding for Siberian development projects may virtually be foreclosed.

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[267] Levine, Richard J. Moscow's Energy Crisis. The Wall Street Journal, August 14, 1975.

[268] Meyerhoff, A. A. Geopolitical Implications of Russian and Chinese Petroleum, op. cit., p. 103.

[269] Levine, Richard J., op. cit.

[270] Laurie, James. American Finance Drying Up. Far Eastern Economic Review, January 31, 1975, p. 63.

The American-Soviet venture closest to realization in Siberia is the North Star project to develop the giant Urengoiskoye gas field in the West Siberian basin. With Export-Import Bank financing no longer a real alternative, the American firms involved in the project (Tennessee Gas Transmission Company, Texas Eastern Transmission Company, and Brown and Root) have turned instead to Western European banks. Favorable response have been received from the Mannesmann group in Western Germany and from banking sources in Britain and France concerning financing the project.[271] The West Europeans are expected to provide about $5 billion in government-backed and supplier credits ($1.4 billion from Britain, $1.9 billion from West Germany, and $1.6 billion from France).

The project would involve the construction of 2,880 kilometer 56 inch gas pipeline from the West Siberian gas fields to a point near Murmansk on the Barents Sea. A liquified natural gas plant, a terminal, and 17 liquified natural gas tankers would also be constructed. Under the plan, gas would be transported to the east coast of the United States at rates of 1.5 trillion cubic feet annually and to Gaz de France at rates of 500 billion cubic feet annually.

The $5 billion financing would cover from 80 to 90 percent of the cost of Western equipment and services with the Soviets paying the balance. An additional $3.5 to $4 billion would be required to construct the liquified natural gas tankers. The gas would be sold to the West at prices competitive with other sources.[272]

This proposal to the Soviets is now under study by the foreign trade ministerial committee which is expected to begin talks with the American group in late May 1976. Even if agreement were reached this year, the project would not begin until 1979 or 1980. A major problem is to obtain the approval of the Federal Power Commission and the Energy Research Council to import such large amounts of gas into the U.S. President Ford has recently called for a limit of one trillion cubic feet per year (about 2.74 billion cubic feet per day) on U.S. Gas imports.[273] Further progress on the project depends upon assurances of White House approval, a most delicate matter in an election year in which U.S.-Soviet detente has become a major issue.

With the anticipated help of U.S. and Japanese commercial banks, the Soviet Union has recently also revived the costly plan to exploit the natural gas deposits believed to exist in the Yakutsk region of Eastern Siberia. The total loans to be provided for the initial exploration phase of the project, which the Soviets had hoped to finance partly through a U.S. Export-Import Bank Loan now stalled by Congressional restrictions, have been scaled down sharply from the original $200 million. A Bank of America syndicate has reportedly agreed to provide $25 million, which will be matched by 23 Japanese commercial banks and Japan's Export-Import Bank for participation in the preliminary phase of the project.[274]

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[271] North Star Revived. Eastwest Markets, May 17, 1976.

[272] Ibid.

[273] North Star Soviet-LNG Project Gets New Life. The Oil and Gas Journal, May 3, 1976, p. 120.

[274] Banks in U.S., Japan Set Loans for Soviet Gas. Wall Street Journal, April 1, 1976.

The Bank of America and Soviet officials signed the agreement in Paris and a parallel loan agreement was signed between the Soviet Union and Japanese representatives.

The loans will reportedly be used to purchase drilling equipment and materials. Prospecting operations will be conducted by Occidental Petroleum Corporation and El Paso Natural Gas Company, a unit of The El Paso Corporation. The companies have been working with the Soviet Union in planning the exploitation of the Yakutsk region for several years, having signed a letter of intent with the Soviets in 1973 for the proposed project.[275]

Originally the Soviets had pledged to finance half of the exploration costs, but it is not clear if they will match the $50 million being provided by the U.S. and Japanese banks. If the project is fully developed, its cost has been estimated at about $7.0 billion.

The terms of the loan are not fully known, but it is understood that the Japanese banks set their interest rate at 6.375 percent over five years, but that the Bank of America's interest rate will be set at around nine percent. It was also understood that both the U.S. and Japan would share in the natural gas when it is produced in Eastern Siberia as was originally planned.[276] The gas exported from Siberia would go to Japan through a 2.720 kilometer pipeline from the Yakutsk region to Russia's east coast. Japan would take half of the gas and the remaining half would go to the U.S. as liquefied natural gas.[277] Under the plan, each country would receive 353 billion cubic feet of gas per year. A fleet of 14 large liquefied natural gas tankers would be required for the imports.

For the United States, however, the benefits of importing Soviet hydrocarbon fuels appear doubtful at best. The price of gas is uncertain and its export would always be subject to the political considerations of the Soviet Union. Thus, such a large investment would, in the opinion of many, be better spent in the United States or in other less sensitive areas of the world.[278]

Japan and the Soviet Union have canceled their plans for oil field development in Western Siberia. The original project envisioned the production of enough new oil to supply an 800,000 barrel per day, 4,150 mile (6,640 kilometer) pipeline between the oil fields of Western Siberia and the port of Nakhodka. Japan was to invest an initial $1 billion with prospects for providing another $2 billion. The Soviets, however, dropped the pipeline project in favor of the construction of a railroad to the port, which lies near the border with China. The proposed railway would run close to the sensitive Sino-Soviet border, a proposal which was unpopular in both China and Japan. Japan has been importing increasing amounts of Chinese crude oil and was unwilling to become involved in the face of Chinese opposition.[279]

Foreign capital could be a key factor in the development of Siberian oil and gas and the question of large scale foreign investment is important for the new five year plan, beginning in 1976. The Soviets are raising their production goals beyond those that Western experts have already judged to be overambitions. The Soviet Oil Ministry has established contacts with American oil companies that could sell the needed technology and equipment to increase Soviet oil output. These companies include: Gulf Oil Company, Standard Oil Company of Indiana, Phillips Petroleum Company, Union Oil Company of California, Mobil Oil Corporation, and Dresser Industries, a maker of oil field equipment.[280]

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[275] Ibid.

[276] Ibid.

[277] Tanner, James C. Russia Revives Plan to Tap Gas Deposits With Aid From U.S. Japanese Banks. The Wall Street Journal, November 19, 1975.

[278] Laurie, James. American Finance Drying Up. Far Eastern Economic Review, January 31, 1975. p. 63.

[279] Japan, Soviets Drop Joint Plan for Tyumen Oilfield Development. The Oil Daily, July 1, 1975.

Mr. Dzandar Tackoev, Soviet Deputy Oil Minister, has forcast an annual increase in oil production during the next five years of at least 600,000 barrels per day. According these figures, production by 1980 would reach at least 12.8 million barrels per day of 640 million tons per year. That figure is well ahead of Western estimates and also is higher than the indicated 1980 target of 600 million tons of oil per year which experts have extrapolated from earlier remarks by Mr. Valentin Shashin, the Soviet Oil Minister.[281]

Most of Western skepticism regarding Soviet ability to meet such optimistic long range production targets is based on an appreciation of the difficulties of operating in Siberia, where the biggest production increases are expected.

However, the development of the oil region of Western Siberia has been rapid despite the extremes of temperatures and undeveloped transportations and power facilities. The Soviet Union is now leading the world in oil production and has achieved this position largely through use of its own technology and equipment.[282] Development of the Western Siberian oil bearing region began with work on railways and roads and on a high tension electrical line brought in from the Urals. A new power station, which operates on casinghead gas, was also constructed. In the taiga, new oil towns such as Nizhnevartovsk, Surgut, Urai, and Nefteyugansk were built. Each of these towns now has a population of from 30 to 60 thousand people and Surgut has been linked with Tyumen by a railroad. This development work has required massive investment. There are almost 4,000 wells in production in Western Siberia. These wells were drilled with Soviet equipment and technology and all Siberian oilfield operations also basically depend upon Soviet equipment.[283] Foreign technology has been used on a limited scale and is expected to be used in increasing amounts in the future, however, Soviet technology has, in general, been equal to the first phase of oil development in the vast region.

Western Siberia, now experiencing a 30 million ton annual increase in oil production is expected to produce about 300 million tons of oil in 1980 (up from 147 million tons in 1975, 3.2 million barrels per day at the end of 1975), according to Oil Minister Valentin Shashin.[284] To accomplish an increase of this magnitude, an infusion of Western technology would appear necessary to assist in the development of the more remote fields and those fields in which production is made difficult by unfavorable geological conditions.

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[280] Ulman, Niel. Western Forecasts of Soviet Energy Crisis Are Erroneous, Russian Oil Official Says. The Wall Street Journal, October 21, 1975.

[281] Ibid.

[282] U.S.S.R. Leans Heavily on Own Resources in Development of Rich Oil Deposits. The Oil Daily, November 20, 1975.

[283] Ibid.

[284] Ibid.

Longer range forecasts to 1990 project a decrease in the dependence on oil from 43 percent (in 1975) to 32 percent of total Soviet energy production and an increase in natural gas utilization from the current 21 percent to 32 percent of total 1990 energy production.[285]

Four-fifths of the projected growth in energy production through 1990 is expected to come from Siberia. The 1990 oil production target is about 750 to 800 million tons. Under this senario, the growth of oil production would be about three percent per year in 1976 to 1990. In the oil industry, the availability of reserves is a more acute problem than in the gas industry, and to expand output in accordance with the projections through 1990 would consume about ten billion tons of recoverable reserves. Thus, maintenance of the estimated 1975 ratio of reserves to production (about 40 to 1) would require the development of about 30 billion tons of explored reserves by 1990.[286] Western Siberia now provides the bulk of the Soviet annual oil production increases and the region reportedly contains almost half of the country's potential oil reserves. Western Siberian output in 1990 is expected to be about 500 million tons or two-thirds of the total Soviet output. This production will require the development of large reserves particularly in the northern part of the region which has great potential, but no major fields as yet. If major fields are not discovered in the northern sections of the West Siberian Basin, new reserves will have to be discovered and developed in East Siberia and in the offshore areas.

The Soviets project an increase in natural gas production to about 900 billion cubic meters in 1990.[287] This would amount to about an eight percent per year addition. In this projection, natural gas would account for approximately two-fifths of the total Soviet energy growth in 1976–1990. Most of this increased output of natural gas is expected to come from West Siberia. A factor limiting the growth of natural gas output is the lack of pipeline capacity to deliver the gas to the Urals and to the European sections of the country.

Although the Soviet Far East also has great gas potential, natural gas output in 1990 is projected from this region at only about 30 billion cubic meters. Potential reserves, located primarily in the Yakutsk region, are earmarked for use in the eastern regions of the Soviet Union and for export, mainly to Japan and possibly also to the United States.[288]

The Soviet Union has recently opened an Arctic sea route from the ice-free North Atlantic port of Murmansk through the Kara Sea to the Yamal peninsula. On March 29, 1976, about three months before icebreakers normally open navigation in the area, the atomic icebreaker Lenin cut through some 560 kilometers of heavy ice to Yamal. The early opening of the sea route is part of a plan to transport Yamal natural gas by tanker of Murmansk. The project is more costly than the exploitation of the large gas and oil deposits in the West Siberia's Tyumen province.[289]

That the Soviets, who have become increasingly concerned about reducing costs would invest in this new and very expensive enterprise gives an indication of the great importance that has been attached to the production of energy resources.

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[285] Soviet Long-range Energy Forecasts. Central Intelligence Agency, September 1975, p. 2.

[286] Ibid. p. 10.

[287] Ibid. p. 8.

[288] Ibid. p. 9.

[289] Wohl. Paul, Soviets Pushing Oil Exploration. The Christian Science Monitor, April 20. 1976.

Summary and Comparisons

With the discovery of the vast hydrocarbon reserves at Prudhoe Bay, the petroleum potential of Alaska is very large. The State may be divided into the following seven petroleum provinces: the Alaska Peninsula—Cook Inlet Province; the Nushagak Lowland and Bristol Bay Tertiary Province; the Bering Sea Shelf Province; the Pacific-margin Tertiary Province; the Yukon-Koyukuk Province; the Arctic Slope Province; and the Yukon Porcupine Province. The U.S. Geological Survey estimated in 1975 that the hydrocarbon potential of Alaska included known reserves of 10.107 billion barrels of oil and 31.867 trillion cubic feet of natural gas, and undiscovered recoverable oil resources of six to 19 billion barrels of oil onshore and three to 31 billion barrels of oil offshore. Undiscovered natural gas resources were estimated at 16 to 57 trillion cubic feet onshore and eight to 80 trillion cubic feet offshore. The low value of the range is the quantity associated with a 95 percent probability that there is at least this amount present, while the high value is associated with a five percent probability of occurrence. The United States is moving with some caution in the exploitation of these Arctic hydrocarbon resources due to environmental considerations. Several lease sales have been scheduled on Federal lands in Alaska, but the sales have been spread over several years. Considering the long lead times required to bring Arctic fields into production and the resistance to exploitation of environmental and other groups, it is probable that many years will elapse before large amounts of oil are derived from this region.

The hydrocarbon regions of Arctic Canada include the Mackenzie Delta, the Beaufort Sea, the Arctic Islands, and the Labrador Shelf. In 1973 the Canadian Society of Petroleum Geologists has estimated that the Beaufort–Mackenzie area contains 64.0 trillion cubic feet of undiscovered natural gas resources. The petroleum industry has reported that the known gas reserves in the region are in the range of 6.2 to 7.9 trillion cubic feet. There is no estimate available for known oil reserves because of a lack of data, however, the industry projects that about 3.8 billion barrels of oil will be discovered by 1990. The 1973 Canadian Society of Petroleum Geologists estimate of the hydrocarbon potential for the Arctic Islands is an undiscovered resource of 23.9 billion barrels of oil and 195.0 trillion cubic feet of natural gas. Drilling already has discovered between 15 and 20 trillion cubic feet of gas and an oil field of unknown size.

The ultimate recoverable oil potential for the entire east coast of Canada was estimated at 47.5 billion barrels by the Geological Survey of Canada in 1973. At the same time east coast ultimate recoverable gas potential was projected at 307.1 trillion cubic feet. There have been two significant gas discoveries on the Labrador Shelf, but whether hydrocarbon prospects there are better than those off the Grand Banks and the Scotian Shelf further south, where about 100 wells have been drilled without the confirmation of a commercial discovery, remains to be determined by future drilling.

The Canadian Government has recently initiated a policy of self-reliance in order to attempt to reduce its dependence on foreign oil. The policy includes measures to increase domestic supplies and to foster conservation. The government plans to allow energy prices to rise to provide the income needed by the industry to increase exploration. The new policy also includes a doubling of exploration and development spending in the northern frontier during the next three years. An indication of Canadian determination to exploit its Arctic regions for energy supplies was its recent decision to allow exploratory drilling in the Canadian section of the Beaufort Sea in the face of the stated environmental concern of the United States.

It is apparent after ten years of drilling that the North Sea is one of the world's major petroleum provinces. The Norwegian Petroleum Directorate now estimates Norwegian potential resources south of 62 degrees north to be between 23 and 30 billion barrels of oil equivalents, with oil and gas in about even quantities. Of this potential, about 7.4 billion barrels of oil equivalents have been measured as commercially exploitable reserves. The Norwegian Petroleum Directorate has further established that the sedimentary rock volumes of the Norwegian Shelf north of 62 degrees north to Svalbard indicate that this Arctic region may contain ten times the amount of oil and natural gas as the shelf south of 62 degrees. This projection is based on extensive geophysical and geological work that has been underway since 1968. The first exploratory drilling north of 62 degrees is planned for the spring of 1977 in the region where the North Sea becomes the Norwegian Sea. The Norwegian Government has picked the two most promising local areas and has indicated that concessions will be granted in time for drilling in 1977. Surveys between 62 and 65 degrees and out beyond the continental shelf proper have been concerned with the Helgeland basins and the Voring Plateau. This region has recently been projected to contain up to 30 billion barrels of oil or its equivalent in natural gas.

In 1974, the Soviet Union overtook the United States to become the world's major oil producer. Western Siberia accounted for about 95 percent of the U.S.S.R. net oil production gain in 1974. Climatic and terrain conditions in the Soviet Arctic are very difficult. The vast region can be divided into the following petroleum regions: the West Siberian Basin, the Pechora Basin, and the East Siberian Province. The West Siberian Basin proved oil reserves have been reported as 87 billion barrels, which is two and one-half times the proved reserves of the entire United States, including Alaska. In 1975 the Soviet Union produced about half as much gas as the United States. The Western Siberian Basin is considered to contain gas reserves in the range of 507 to 787 trillion cubic feet. The largest gas field in the world, the West Siberian Urengoiskoye, may have ultimate reserves considerably larger than all current proved gas reserves in the United States.

The West Siberian Basin is the world's largest sedimentary basin and contains an oil generating area the size of the State of Texas calculated to have a generating potential of about 24 trillion barrels of oil. It appears that the oil recoverable from a sedimentary basin is no greater than ten percent of the amount generated, but that three percent is usually a more representative number. On this basis, the ultimate potential of the West Siberian Basin could amount to a staggering 720 billion barrels of oil equivalents.

The Pechora Basin is located west of the Urals in the Soviet Arctic and extends northward beneath the Barents Sea. Proved Pechora Basin reserves are 1.5 billion barrels of oil and 45 trillion cubic feet of natural gas. The ultimate potential for the basin, both onshore and offshore, is considered to be at least 50 billion barrels of oil and 500 trillion cubic feet of gas. The operational problems present in the West

Siberian Basin, due to the climatic extremes and remote location, are also present in the Pechora Basin. Currently, the petroleum exploration rate in this basin appears to be lagging behind schedule due to a lack of equipment, as most available equipment is being utilized in the West Siberian Basin.

The East Siberian Province covers a vast territory of more than three million square kilometers between the Yenisey and the Lena Rivers. Potential oil and gas bearing regions occur in areas where the sedimentary cover is downwarped. In the Yakut area, drilling has confirmed a gas reserve of 452 trillion cubic feet, but commercial amounts of oil have not as yet been found.

The Soviet Government is committed to the rapid development and eploitation of the West Siberian Basin, excluding its offshore extension beneath the Kara Sea. Of secondary, but nearly equal, priority is the development and exploitation of the Pechora Basin, excluding its extension offshore beneath the Barents Sea. Third in priority among the Arctic regions is the East Siberian Province. Foreign capital and technology could be a key factor in the development of Siberian oil and gas as the Soviets are raising their production goals beyond those that have already been judged overambitious by Western experts. The Soviets have established contact with Western oil companies and banks that could provide needed financing and technology to increase Soviet Arctic oil and gas development.

A summary of Polar known and potential oil and natural gas reserves (including Antarctica) is given in Table 4. For comparison, the values for the United States and for the non-Communist world are also given. It can be seen that the Polar areas of the world contain vast amounts of oil and gas. The known oil reserves in the Polar region are almost three times as great as those of the United States. Natural gas reserves in the Polar regions appear even more significant, almost equaling the gas reserves of the entire non-Communist world. It is apparent that oil and gas exploration and exploitation in Polar regions will become more commonplace as hydrocarbon resources are depleted in the more temperate latitudes. Thus, the technology of Polar oil and gas operations and transportation can be expected to undergo continuing research and development.

TABLE 4.—POLAR OIL AND NATURAL GAS

Area	Oil (billion barrels)		Gas (trillion cubic feet)	
	Known	Potential	Known	Potential
Antarctica		15		115
Alaska	10.107	[1] 6–19 [2] 3–31	31.867	[1] 16–57 [2] 8–80
Arctic Canada		51	21.2–27.9	413
Arctic Norway		125–150		725–870
Arctic Russia	88.5	410+	1,004–1,284	2,588+
Total	98.607	676+	1,057–1,344	4,123+
United States (total on and offshore)	38.886	50–127	237.132	322–655
Non-Communist world	604.3		1,709	

[1] Onshore.
[2] Offshore.

Note: The values in the polar portion of above table are taken from and referenced in the text. The total U.S. values are taken from: Miller, Betty M. et. al. "Geological Estimates of Undiscovered Recoverable Oil and Gas Resources in the United States." Geological survey circular 725, Reston, Va., 1975, pp. 28–31. The known oil and gas reserves from the non-Communist world were taken from: "Worldwide Oil at a Glance." "The Oil and Gas Journal," Dec. 30, 1974, pp. 108–109.

It must be noted, however, that the figures in the table are, for the most part, estimates. This is obviously true for all of the potential deposits. The techniques used to estimate the potential oil and gas that may be discovered and produced in Alaska are much more conservative (and probably more accurate) then those used to estimate the undiscovered potential in Norway and the Soviet Union and, to a certain extent, even in Canada. The known deposits in the Soviet Union also have a slightly different definition than in the United States which tends to inflate Soviet reserve figures. In spite of these differences, however, Arctic hydrocarbon resources remain immense, with the greatest amounts located outside of the United States. In these foreign regions, exploitation will be stressed with the possible exception of Norway, which is self sufficient in energy at the present time. Thus, Arctic oil and gas exploration, production, and transportation technology will be advanced and the resources will become available.

HYDROELECTRIC POWER

ALASKA

RESOURCES AND EARLY DEVELOPMENT

The hydroelectric power resources of Alaska are large, but less than one-third of one percent have been developed. Excluding pumped storage, the potential average annual generation is 172.7 billion kilowatthours from a potential installed capacity of 32.6 million kilowatts.[1] The Alaskan hydroelectric power resources represent about one fourth of the total potential hydroelectric power generation of the United States. Most of this potential power is located in the Kuskokwim and Yukon River basins. By comparison, the water power potential of the northern part of the state is quite small. Southeastern Alaska contains a large number of small potential hydroelectric power sites (Figure 12). Alaskan waterpower inventory studies have identified over seventy favorable sites. Table 5 lists 15 possible projects which appear to have the greatest likelihood of future development in terms of long range State and national needs.

The first hydroelectric project in Alaska was constructed in 1901 and supplied electricity to the city of Ketchikan. In many communities, industrial and commercial power installations were originally the only sources of electricity. Many of the original hydroelectric plants are still in operation and some of Alaska's present utility systems are derivatives of earlier industrial and commercial enterprises such as mining, lumbering, canneries, etc. The present trend is toward increasing generation by public utilities.

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[1] Federal Power Commission. Annual Report 1974. Washington, D.C., 1975, p. 87.

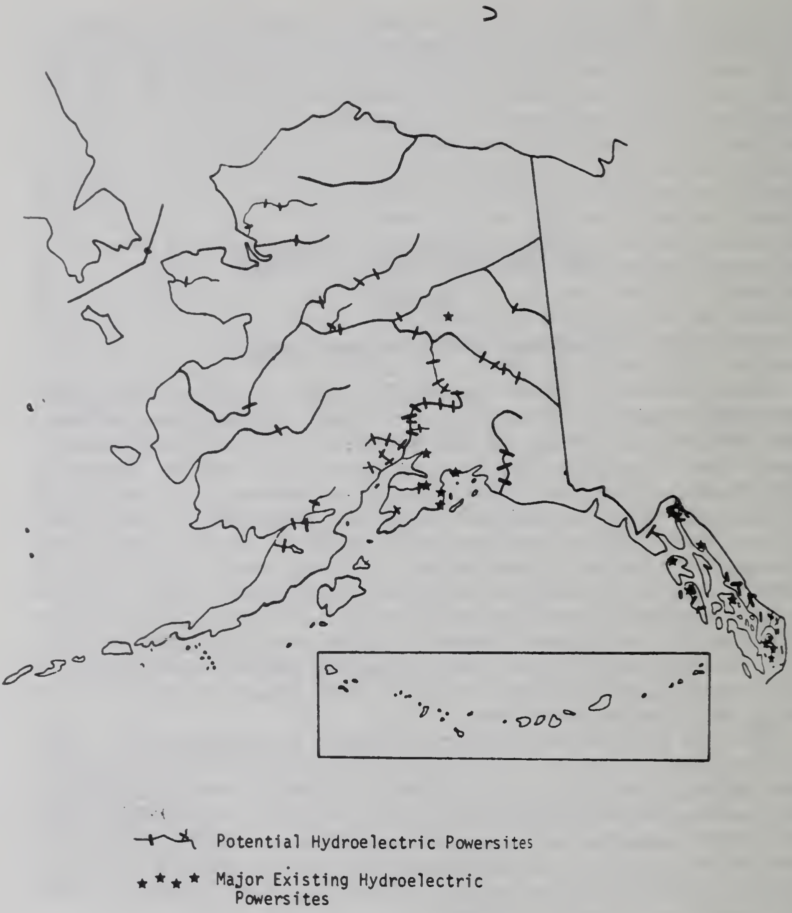
Potential Hydroelectric Powersites
Major Existing Hydroelectric Powersites

FIGURE 12.—HYDROELECTRIC POWERSITES IN ALASKA.

Source: U.S. Federal Field Committee for Development Planning in Alaska. Economic Outlook for Alaska, Anchorage, 1971, p. 247.

TABLE 5.—HYDROELECTRIC RESOURCES OF ALASKA

Project	Stream	Annual firm energy (kilowat hours times 10^6)
Agashashok	Noatak River	820
Holy Cross	Yukon River	12,300
Ruby	do	6,400
Rampart	do	34,200
Porcupine	Porcupine River	2,320
Woodchopper	Yukon River	14,200
Yukon-Taiya	do	[1] 21,300
Crooked Creek	Kuskokwim River	9,400
Chakachamna	Chakachatna River	1,600
Devil Canyon, Watana, Vee, Denali [2]	Susitna River	7,000
Bradley Lake [3]	Bradley River	368
Wood Canyon	Copper River	21,900

[1] Development of Yukon-Taiya would diminish energy potential of downstream sites on the Yukon River.
[2] 4 units of Upper Susitna project.
[3] Authorized project.

Source: Federal Power Commission. Alaska Power Survey. Preliminary draft of the Report of the Executive Advisory Committee. May 1974, p. 59.

HYDROELECTRIC DEVELOPMENT BY THE FEDERAL GOVERNMENT

The Eklutna Project, a 30,000 kilowatt hydroelectric plant serving Palmer and the Greater Anchorage area, completed in 1955, was the first Federal hydroelectric project in Alaska. In 1962, the U. S. Army Corps of Engineers was assigned responsibility for engineering design and construction of Federal hydroelectric power projects in Alaska. The Alaska Power Administration was established in 1967 as a separate bureau of the Department of the Interior, headquartered in Alaska, to promote the development and utilization of water, power, and related resources of Alaska.

CONSIDERATIONS FOR FUTURE DEVELOPMENT

Alaska's electric power industry is fossil-fuel oriented. The readily available coal, gas, and oil energy sources, make fossil-fuel powerplants competitive with hydroelectric plants. The small population and limited industries in Alaska will also limit the development of hydroelectric power in the future, particularly in the northwest region.[2] Investment costs for hydroelectric projects are high, and it would be reasonable to expect that those developed in the future would be major projects appropriate for Federal financing.

In comparison with thermal-electric or nuclear plants, hydroelectric plants have several advantages: they do not consume or heat the water they use, and they do not contribute to air pollution. Maintenance costs are relatively low, and it is possible to design hydroelectric plants for virtually automatic operation. Adverse effects may be interference with fish and wildlife.[3]

TIDAL POWER

Another possibility for generating hydroelectric energy in Alaska is from the extraordinary tidal range in Cook Inlet. The tides at the entrance have a mean range of approximately 4.3 meters (Port Graham 14.4 feet) while at Anchorage this has increased to 7.6 meters. The increase in amplitude is likely due to both the funneling effect of decreasing width and resonance effects of the tide entering the inlet. Several tidal power schemes for Cook Inlet have been proposed in the past.[4] One of the more ambitious proposals would theoretically generate about six percent of the entire electrical energy production of the United States. While the engineering difficulties for such a proposal would be immense, they do not seem insurmountable. The basic question is how could such huge blocks of energy be stored and integrated into the U.S. supply network. Most proposals for harnessing the tides in Cook Inlet have been dropped for lack of sufficient electrical demand in the area. Other factors that would present difficulties are the large amounts of drift ice in the winter, plus the heavy silt load of the water entering Cook Inlet, and the region is geologically active so that Earth movements may be expected.

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[2] Sater, J. E., Ronhovde, A. G. and L. C. Van Allen. Arctic Environment and Resources. Arctic Institute of North America, Washington, D.C., 1971, p. 205.

[3] The largest hydroelectric project considered for Alaska was the Rampart Project on the Yukon River, which was shelved in the absence of demand for much of the power it would produce, availability of favorable low-cost power alternatives, and significant adverse effects on fish and wildlife.

Arctic Canada

Although thorough surveys have not been made, partial surveys indicate there is considerable potential for hydroelectric power development in Canada north of 60 degrees. The areas that are particularly favorable for water power development are along the Yukon River, the rivers flowing into the Great Slave Lake, and the South Nahanni River which drains into the Mackenzie River. An indication of the magnitude of the resource potential is given in one statement that compares the water flow in the four principal Canadian arctic basins as approximately equal to two Fraser Rivers, one Columbia River, and one St. Lawrence River.[5] The available continuous power of the undeveloped water power resources in the Canadian Arctic is estimated at 9,011,000 kilowatts at 88 percent efficiency of the arithmetical mean flow.

Water power is of special importance in the Yukon Territory and Northwest Territories in the development of mining areas such as Mayo and Yellowknife. There are four hydroelectric generating plants operating in the Yukon and four in the Northwest Territories. Total installed hydroelectric generating capacity for the Canadian Arctic is 63,000 kilowatts, of which 28.000 kilowatts is in the Yukon Territory and 35,000 kilowatts in the Northwest Territories.

High tides, ranging from six to 12 meters, are found along the Hudson Strait and approach 18 meters in height along the west side of Ungava Bay.[6] The hypothetical tidal power resource potential of Ungava Bay is estimated to be on the order of 6.5 trillion kilowatt-hours per year. However, the expense and engineering problems of fully developing this potential resource would be immense.

Greenland

Although the Danes are surveying the Greenland coast for sites of hydroelectric power generation, there has been little development of the hydropower resources of Greenland. On the other hand, since most fuel has to be imported, any possible development of hydroelectric resources for local use would be helpful. Estimates of potential hydropower resources of Greenland run as high as 11 million kilowatts.

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[4] Wilson, E. M. and M. C. Swales. Tidal Power From Cook Inlet, Alaska. In Tidal Power, edited by T. J. Gray and O. K. Gashus. Plenum Press, New York, 1972, pp. 239–256.

[5] Sater, et. al., op. cit., p. 232.

[6] Ibid., p. 88.

ICELAND

Rivers and waterfalls are one of Iceland's most valuable resources. Only a small fraction of the hydroelectric power potential, estimated at 35 billion kilowatt-hours annually, has yet been harnessed. Currently, the country is encouraging development of energy-intensive industries to utilize inexpensive hydroelectric power from proposed government hydroelectric projects.[7] Industrial projects under consideration include a sea chemicals complex and several minerals processing plants. An aluminum refining plant at Straumsvik was completed in 1969, and expanded since, powered by a large hydroelectric plant at Burfell on the Thjorsa. Iceland utilizes its inexpensive hydroelectric power resources by importing ores and exporting refined metals. In a sense, Iceland is exporting hydroelectric power.

NORWAY

Norway's total hydroelectric power potential is estimated at about 15 million kilowatts. Prior to the recent oil and gas discoveries in the North Sea, Norway had no oil and its coal production from Spitsbergen is inadequate to meet its power needs. Consequently, great emphasis has been placed on development of hydroelectric resources. By 1964 Norway had the highest per capita consumption of electricity in the world, twice that of the United States. About 44 percent of Norway's electrical production is for residential use.

SWEDEN

While Sweden's fossil fuel resources are meager, it is compensated by large resources of hydroelectric power. The country is estimated to have a developable potential capacity of some 20 million kilowatts and a potential annual generation of 85 billion kilowatt-hours, of which over half is being utilized. Over 80 percent of Sweden's waterpower resources are in Norrland, a vast region occupying the northern two-thirds of the country, while much of the demand for power is in the south. Consequently, the Swedes have constructed some of the longest high-tension transmission lines in the world to bring power south. Sweden's power grid is also linked into those of Norway, Finland, and Denmark.

About one-seventh of Sweden lies north of the Arctic Circle. The economically developable hydroelectric potential of this region is estimated at 14.6 billion kilowatt-hours per year.[8] There are several hydroelectric power plants located in Arctic Sweden, two of these are at Porjus and Harspranget. A 1,000 kilometer, 400 kilovolt transmission line connects Harspranget with Hallsberg in southern Sweden. A one million kilowatt station is planned near the Norwegian border, in the vicinity of Narvik.

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[7] U.S. Bureau of Mines. Minerals Yearbook 1972. vol. III, Washington, 1974, p. 973.
[8] Sater, et. al., op. cit., p. 287.

In an attempt to further develop its hydroelectric power resources and reduce dependence on imported oil, Sweden is experimenting with mini-hydroelectric power plants. The Swedish Power Plant Association plans to build about 300 small standardized plants to be used on minor rivers and watercourses. These plants would be provided with automatic monitoring and control equipment and not require permanent manning.

Finland

Hydroelectric power is one of the main sources of energy for Finland. Finland lost one third of its electric power capacity to the Soviet Union, but the harnessing of rivers and rapids in northern Finland has offset the losses. The Finnish Arctic has a large potential for the generation of hydroelectric power. One hydroelectric project that has been proposed would create artificial lakes in the region north of Sodankyla, and a regulation basin at Kemijarvi, to produce around 5.5 billion kilowatt-hours annually.[9]

Arctic Russia

RESOURCE POTENTIAL AND GENERATION CAPACITY

The potential hydroelectric power resources of the Soviet Union are immense, but in the over all Soviet energy economy hydroelectric power is of relatively small significance. Hydroelectric powerplants supplied 123 billion kilowatt-hours or 14.4 percent of all electric power generated in 1972, compared with 15.6 percent during 1971. Total hydroelectric generation capacity reached 35 million kilowatts at the end of 1972. Potential Soviet hydropower resources are given in Table 6 and located on the map (Figure 13). Only a fraction of these resources are likely to be developed in the forseeable future. One reason is that only 18 percent of the economically developable hydropower resources are located in European U.S.S.R., where the demand is greatest, and the largest rivers there have already been developed. The Russians do not possess the technology for harnessing average and small-size rivers with irregular flow.[10] While the hydroelectric resources potential of the Siberian Arctic is enormous, most of this resource potential is on the downstream portion of rivers, near the Arctic Ocean, far from centers where the power would be needed. Technical difficulties and expenses involved in construction of the power generating facilities and the long-distance transmission lines to the energy demand centers will hamper possible future development. Two areas where future hydropower development will likely occur are along the Yenisey and Angara rivers near locations where large mineral resources are found. The headwaters of these rivers are already utilized for hydroelectric power generation.

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[9] Ibid.

[10] Slocum, M. Soviet Energy: An Internal Assessment. Technology Review October/November 1974, p. 22.

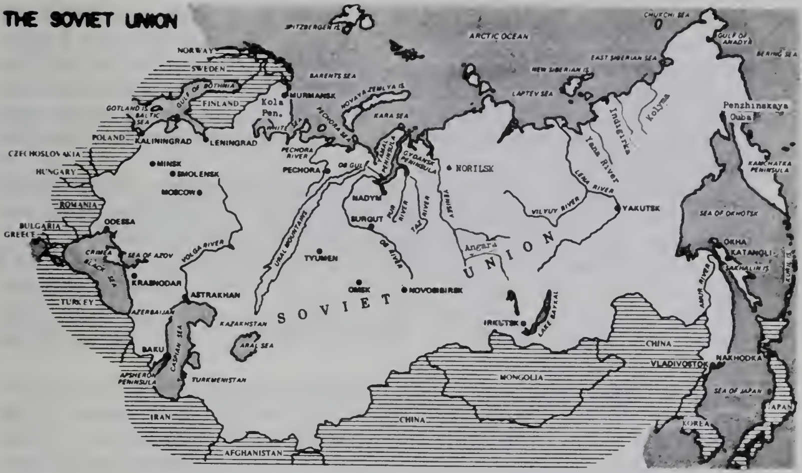

FIGURE 13.—Soviet hydropower resources.

TABLE 6.—POTENTIAL HYDROPOWER RESOURCES OF THE SOVIET UNION

	Economical hydropower resources		Technically feasible hydropower resources		Potential hydropower resources		Percent utilization of hydropower resources		
	Billion kilowatt-hour	Percent of total	Billion kilowatt-hour	Percent of total	Billion kilowatt-hour	Percent of total	1965	1970	Projected 1980–85
European U.S.S.R.	192	17.5	298	14.0	562	16.7	8.5	10.4	16.7
West Siberia and Central Asia	(1)	--------	(1)	--------	(1)	--------	(1)	(1)	(1)
East Siberia	350	32.0	664	31.5	848	25.0	2.16	4.7	12.5
Far East	294	26.9	684	32.5	1,009	33.0	0	.08	.7
Total for U.S.S.R.	1,095	100.0	2,106	100.0	3,338	100.0	2.4	3.4	7.8

[1] No estimates provided.

Note: Soviet potential hydropower resources are huge, yet only a fraction of these can be developed in the foreseeable future. Remoteness, technical and economic problems, and—in many instances—arctic climate preclude the development of most potential hydropower resources.

Source: Slocum, op. cit., p. 23.

On the Kola Peninsula, hydroelectric plants on the Niva, Tuloma, and Paz rivers supply about 70 percent or about 4.2 billion kwh of the energy for industry in the region. Several hydroelectric power stations are located around the White Sea. These include the Vyg River system with a capacity of 230,000 kilowatts, the Kenn River system with a capacity of 250,000 kilowatts, and the Kovda-Kuma system with a total capacity of 300,000 kilowatts.[11]

The potential power resources of the Pechora, Vychegda, and Mezen rivers are estimated at 22 billion kilowatt hours during a year of average water flow.[12] There are plans for construction of a 1.5 million kilowatt hydroelectric plant at Ust' Izhma, on the Pechora River at the mouth of the Izhma.

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[11] Sater, et. al., op. cit., p. 256.
[12] Ibid., p. 256.

There has been little hydroelectric power development in the western Siberian Arctic. Plans for a six to seven million kilowatt hydroelectric plant on the Lower Ob just above Salekhard were opposed because the vast lowland reservoir would flood future valuable farmlands, interfere with the development of other resources (such as oil, gas, and timber), and cause adverse effects on the regional water balance, climate, and soils.[13]

One of the Soviet Union's northernmost hydroelectric power plants, the 441,000 kilowatt hydroelectric station on the Khantayka River, provides much of the power for the Norilsk mining area.

In central Siberia, the diamond industry at Aykhal is served by a 312,000 kilowatt hydroelectric station on the Vilyuy River at Cherny-Shevskiy. Plans are underway to construct a series of seven huge hydroelectric power plants on the Lena River, one of them on the lower river near Tiksi.

Several plans have been drawn for dams and hydroelectric projects in eastern Siberia. These projects include water-power dams on the Yana, Indigirka, and Kolyma rivers, as well as on Chukotshiy Poluostrov. In addition, hydroelectric plants are also planned at Kolymskaya on the lower Kolyma and on the River Amguyema, which empties into the Chukchi Sea.

Soviet hydroelectric power technology appears to be reasonably modern and effective. Western observers of Soviet efforts—such as U.S. delegations—seem to be favorably impressed. The Russians appear to be able to compete in the world market for this kind of equipment. They have sold turbogenerator units for hydroelectric plants to several developing countries, have bid successfully in the Canadian market, and have been considered a threat in the U.S. market.[14]

TIDAL POWER DEVELOPMENT AND TECHNOLOGY

Of an estimated worldwide tidal power potential of 1,240 billion kilowatt-hours per year, the U.S.S.R. has a large share at 210 billion kilowatt-hours per year.[15] Of particular interest is the power resource potential of the White Sea (40 billion kilowatt-hours per year) which the Soviets would like to draw on to supply much needed power to European U.S.S.R. At the end of 1968, a small experimental tidal power plant was put into operation at Kislaya Guba, a small bay 970 kilometers north of Murmansk. The Kislaya Guba tidal power station was designed to accommodate two reversible flow tidal generator turbines, one built in France and the other to be built in Russia, for a total capacity of 800 kilowatts.

Because the most favorable sites on the White Sea for locating tidal power plants are in uninhabited regions where the climate is severe, on-site construction is difficult and expensive. For this reason the Russians chose the float-in-place method for the Kislaya Guba tidal plant which involves constructing the plant at an industrial center and floating it to the site in a finished form. The plant was built at Cape Prityka near Murmansk.

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[13] Ibid., p. 256.

[14] Campbell, R. W. Technological Levels in the Soviet Energy Sector. East-West Technological Co-operation, Colloquium–1976, NATO Directorate of Economic Affairs, Brussels, March 17, 18, 19, 1976. p. 13.

[15] Bernshtein, L. B. Kislaya Guba Experimental Tidal Power Plant and Problem of the Use of Tidal Energy. In Tidal Power, edited by Gray, T. J. and O. K. Gashus. Plenum Press, New York, 1972, p. 217.

There are plans for construction of a 320,000 kilowatt tidal station at Lumbovka Bay, on the north shore of the Kola Peninsula, 320 kilometers southeast of Murmansk. A 1,300,000 kilowatt tidal power station at the mouth of the Mezan River and a 500,000 kilowatt plant at the mouth of the Kuloy River are also planned. Presumably, if these plants are constructed, they would also be prefabricated at Murmansk and floated to the prepared sites. A very large-scale project with an installed capacity around 20,000,000 kilowatts has been proposed at Penzhinskaya Guba on the Sea of Okhotsk requiring a dam 31.4 kilometers long.[16]

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[16] Wilson. E. M. Energy From the Sea—Tidal Power. The Underwater Journal, August. 1973, p. 175–186.

GEOTHERMAL ENERGY

INTRODUCTION

From surface indications such as volcanoes, hot springs, geysers, and fumaroles, it is evident that there are certain geographical regions of the earth's crust beneath which geothermal fluids occur. These regions occur at belts which are geologically unstable, possessing a high earthquake incidence. One of the belts lies along the western side of the Americas extending from Chile north to the Aleutian Islands. This is part of the circum-Pacific "ring of fire" of volcanic, earthquake, and geothermal activity, which surrounds the Pacific Ocean and continues along the eastern coast of the Soviet Union and south through Japan, the Philippines, Indonesia, and New Zealand. Another belt of volcanic activity is the mid-Atlantic ridge upon which Iceland, with its large geothermal resources is situated.[1]

Geothermal energy is potentially available in these active belts, depending upon local geologic, geographic, and economic conditions. Geothermal fluids cannot be transported far from their point of recovery because heat dissipates rapidly. The maximum transport distance depends upon the heat content of the fluid and the use for which the fluid is intended. For steam used in electric power generation, the probable maximum distance is in the range of two to three kilometers. Hot water for space heating or agricultural use can be transported farther. In Iceland, municipal hot water is transported a reported distance of 20 kilometers.[2]

Conversion to electrical power is a practical means of transferring heat energy from the more remote geothermal fields to populated areas, however the price of conversion is a substantial loss of energy and further losses occur in transmission. Thus, greater efficiency results from a more local utilization of the electricity produced from geothermal energy.

The technology for utilizing dry-steam geothermal deposits for electrical power production by routing the steam directly through the turbines is reasonably well advanced. There are several areas in the world where dry geothermal steam is used in this manner, notably the Geysers area in California and Lardarello in Italy. Geothermal deposits which consist of both steam and hot water combined can also be exploited for electric power, either by partially flashing the hot liquid into usable steam at the surface or by transferring its heat to a secondary working fluid, such as freon, which is used to turn the turbines. The remaining hot water fraction can be used for space heating or for industrial purposes. Wet-steam and hot water electric power plants are more expensive that the dry-steam plants, but such deposits are much more common in nature. The technology is reasonably, but not totally developed, as corrosion remains a major problem. Cerro Prieto, Mexico; Wairakei, New Zealand; and Kamchatka, U.S.S.R. are areas in which wet-steam deposits are being utilized to produce electricity.[3]

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[1] Riva, Joseph P., Mielke, James E., Dyas, Norma W., and Justus, John R., op. cit., p. 32.

[2] Kruger Paul and Otte Carel. Geothermal Energy. Stanford University Press, Stanford, California, 1973, p. 17.

NORTH AMERICAN ARCTIC AND GREENLAND

Alaska offers good geological potential for geothermal development in that it appears to have at least ten volcanic regions in which the rock systems contain large amounts of thermal energy. The southeastern section of Alaska, the Wrangell Mountains, the Alaskan Peninsula, and the Aleutian Islands contain hot springs and area of relatively recent volcanic activity as general indicators of potential geothermal deposits. Approximately 100 thermal springs have been recognized in Alaska.

The U.S. Geological Survey has designated 88,160 acres in Alaska as, "known geothermal resources areas." The localities are Pilgrim Springs in the Seward Peninsula and the Geyser Spring Basin and Okmok Caldera on Umnak Island in the Aleutians. A known geothermal resources area is defined by the Survey to be an area in which the geology, nearby discoveries, competitive interests, or other indicia would, in the opinion of the Secretary of the Interior, engender a belief in men who are experienced in the subject matter that the prospects for extraction of geothermal steam or associated geothermal resources are good enough to warrant expenditures of money for that purpose. An additional 11,277,000 acres, located in the Seward Peninsula and in the Aleutian Islands, have been classified by the Geological Survey as having prospective value for geothermal resources.

Thus, the Aleutian Chain and the Seward Peninsula may well have significant potential for geothermal power. To Nome, and other localities on the Seward Peninsula which lack other fuel resources, a geothermal resource may be of benefit not only for the generation of electricity, but also for space heating and for horticulture.[4] In the central section of Alaska there has been current and historic use of hot springs for bathing and limited agricultural purposes. Pilgrim Springs (located approximately 80 kilometers north of Nome) is currently being investigated by private interests for the production of electricity for the city of Nome, nearby gold mining operations, and a proposed fluorite development 160 kilometers (100 miles) to the northwest.[5] The Alaskan Peninsula and the Aleutian Island volcanic belt contain 34 of Alaska's approximately 100 thermal springs and more than 40 recently active volcanoes.

The southeastern portion of Alaska contains about 80 percent of the State's population and is currently deriving its energy from hydropower, coal, oil, and natural gas. The area contains over twenty thermal springs, the most significant concentration of which are located in the Alexander Achipelago. According to sodium-potassium-calcium temperature curves, reservoir temperatures of some of the southeastern Alaska thermal springs could be as high as 170 degrees centigrade which suggests that this area deserves further exploratory attention. Another favorable factor for this region is that nearly all of the thermal springs are near the ocean, thus transportation costs for ultimate energy utilization for commodity import or export are enhanced.[6]

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[3] Riva, Joseph P., Mielke, James E., Dyas, Norma W., and Justus, John R., op. cit., p. 19.

[4] Economic Outlook for Alaska. U.S. Federal Field Committee for Development Planning in Alaska, Anchorage, Alaska, 1971, p. 245.

[5] Rosenbrunch, Jimmie C. and Bottge, Robert G. Geothermal Energy: Economic Potential of Three Sites in Alaska. Bureau of Mines Information Circular 8692, 1975, p. 4.

The U.S. Geological Survey has estimated that the heat content of the identified thermal water convection systems in Alaska amounts to about 6.3 x 10^{18} calories (10^{18} calories is equivalent to the heat of combustion of about 690 million barrels of petroleum or 154 million short tons of coal) while the identified high temperature hydrothermal convection systems in Alaska have an electrical energy equivalent of about 38 megawatt century (a megawatt century is an amount of energy equal to 1,000 kilowatts produced continuously for 100 years).[7]

This potential has yet to be realized as geothermal development, such as leasing and exploration drilling, which are slowly getting started in the western portion of the lower 48 States, but have not as yet exhibited much activity in Alaska.

Arctic Canada lacks some of the geological potential for geothermal energy that exists in Alaska. There are five recognized thermal springs in Alberta and 32 in British Columbia, but none have been reported in the Arctic regions of Canada.[8] In the Yukon and the Northwest Territories water power is of special importance with future energy requirements considered well assured if proper care is exercised developing this resource.[9] Thus, the combination of relatively unfavorable geology and other readily available energy resources has resulted in little interest in geothermal development in Arctic Canada.

Greenland, like Arctic Canada, appears to be geologically unfavorable for geothermal development. The main part of Greenland is considered to be an elevated portion of the stable Canadian Shield [10] rather than an area of volcanic and earthquake activity such as is usually associated with geothermal resources. However, Greenland is still relatively unexplored and three thermal springs have been reported on the island.[11] It is possible that geothermal energy could be used on a small scale locally, for example for space heating, if proper local geological conditions are found.

ICELAND

Iceland, located on the volcanically active mid-Atlantic ridge, has long been utilizing geothermal energy for space heating and for greenhouses. The country has a cold climate which requires houses to be heated for about 330 to 340 days per year. No fossil fuel resources are available on the island except for limited reserves of peat and lignite. Geothermal areas, however, are abundant with 516 reported thermal springs. and a number of major steam fields. The first attempts at heating single houses were made at the beginning of this century and by 1925 hot spring water was used for vegetable greenhouses. The first boreholes for hot water were drilled about three kilometers from the capital, Reykjavik, in 1928 and a pipeline was constructed to the city to feed a pilot heating district comprised of 70 houses, two swimming pools, and a school.[12] More extensive drilling for hot water began in 1933 at the Reykir thermal spring area, about 18 kilometers outside Reykjavik.

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[6] Ibid. p. 5.

[7] White, D. F. and Williams, D. L. Assessment of Geothermal Resources of the United States—1975. Geological Survey Circular 726, Reston, Virginia, 1975.

[8] Warning, G. A., op. cit.

[9] Sater, John E., Ronhovde, A. G., and Van Allen, L. C. Arctic Environment and Resources. The Arctic Institute of North America, Washington, D.C., 1971, p. 232.

[10] Sater, John E. The Arctic Basin. The Arctic Institute of North America, Washington, D.C., August 1969, p. 67.

[11] Warning, G. A., op. cit.

Between 1939 and 1943 a new district heating system was constructed serving 2,300 houses (about 30,000 people) and all public buildings. The system included an 18 kilometer transmission pipeline, pumping stations, water storage tanks, and underground distribution networks beneath the streets. It was completed in December of 1943 and is still in operation. The system was extended in 1949 and 1950 after additional drilling three kilometers north of Reykir. A total of 72 thermal wells varying in depth from 300 to 770 meters were in use at this time, producing a total of 330 liters per second of 86 degrees centigrade water. The Reykir fields have been producing continuously for over 35 years with a total production rate in the order of 300 million cubic meters of water without any drop in temperature or decrease in production rate.[13]

Two additional thermal areas have been delineated within the city limits of Reykjavik since 1950 and the city heating system has thus been greatly expanded. Reykjavik is now almost totally heated by geothermal waters. Its municipal heating system serves about 85,000 people. The wellhead water temperatures range from 80 to 140 degrees centigrade. The hot water is mixed with retour water which lowers its temperature to 75 to 80 degrees centigrade as it enters the radiators in the houses. It is wasted at 35 to 40 degrees. The cost of heating in Reykjavik is only about 60 percent of that of fuel oil heating.

Currently about 46 percent of the total Icelandic population live in houses centrally heated by natural hot water and plans call for this figure to be increased to 65 percent before the end of the decade. Some other towns having natural hot water heating systems are: Olafsfjordur, in northern Iceland; Selfoss, in southern Iceland; Hveragerdi, also in southern Iceland; and Saudarkrokur, in northern Iceland. Since about 1930, elementary and secondary boarding schools in the rural areas have, when possible, been located in geothermal areas where they can be geothermally heated and equipped with swimming pools. They are also often self-supporting with vegetables grown in geothermally heated greenhouses.

Over 120,000 square meters of greenhouses throughout the country are heated by natural hot water. These greenhouses provide vegetables and flowers for domestic market. The total use of natural heat for this purpose in Iceland corresponds to about 20,000 tons of fuel oil per year.[14] Several fish breeding stations use geothermal water. Geothermal steam is used to process diatomaceous earth and in an experimental electrical power plant at the Namafjall thermal field. The plant began producing electricity in 1969 and has a capacity of three megawatts. A 50 megawatt geothermal steam plant is planned for 1977 at Krafla in north central Iceland. The gross production of geothermal energy in Iceland in 1973 was equivalent to burning 360,000 metric tons of fuel oil per year.[15]

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[12] Einarsson, Sveinn S. Geothermal District Heating. Gothermal Energy, UNESCO, Paris, 1973, p. 124.

[13] Ibid.

[14] Bjornsson, Sveinbjorn. Utilization of Thermal Energy in Iceland. House Committee on Science and Astronautics. Subcommittee on Energy, Hearings on H.R. 8628 and H.R. 9658, Sept. 11, 13, and 18, 1973, p. 358.

Other uses for geothermal fluids are being considered in Iceland. An experimental salt recovery process proved uneconomic and was discontinued. There is a pilot operation to dry seaweed, utilizing 100 degree centigrade geothermal water, for recovery of alginates. A geothermal brine with the approximate composition of sea water is being studied for the recovery of various chemicals including magnesia, table salt, and bromine. Freeze drying of fish, Iceland's main export, by use of geothermal energy is also being evaluated.[16]

Following recent volcanic eruptions in the Westman Islands, ash deposits were removed from the hot lava and pipes with heat exchangers were installed and water circulated to heat homes and a planned hospital. This appears to be the first reported utilization of a hot dry rock geothermal resource.[17]

High temperature geothermal fields occupy north-south zones of crustal rifting and active volcanism on Iceland. Outward east and west from these zones are extensive sheets of Late Tertiary age basalts from which abundant warm and hot springs issue. The high temperature reservoirs are associated with the main Quaternary age rift and also with Late Quaternary age centers of rhyolitic volcanism rather than with the basalts. Permeability within a reservoir may be controlled by lithology or by fractures, but thermal emissions to the surface are usually fracture controlled.[18]

Exploration of Iceland's thermal areas is currently being carried on by geological, geophysical, and geochemical methods as well as by drilling and by hydrological studies.

NORWAY, SWEDEN, AND FINLAND

The Scandinavian Arctic is geologically unfavorable for the discovery of geothermal waters. It is not tectonically active and no thermal springs have been reported in the area.

ARCTIC RUSSIA

Geothermal research in the Soviet Union began in the first half of the 18th century with several scientific expeditions engaged in measuring temperatures in various mines in Siberia, the Urals, Altay, the Volga regions, and in the Far East. In 1906 methods for geothermal prospecting and the exploitation of hot mineral waters were developed. Following the revolution, geothermal research was given practical and scientific attention in national planning, though on a moderate scale and at a slow pace. By the early 1940's research was directed toward the development and exploitation of mineral and thermal springs. In 1963, the Plenum of the Central Committee of the Communist Party enacted a resolution to intensify research on the utilization of geothermal resources primarily in Kamchatka, and subsequently in Siberia, the Caucasus, and other regions of the Soviet Union. To coordinate these activities, the Earth Sciences Section of the Soviet Academy of Sciences was reorganized in January 1964 into the Scientific Council for Geothermal Research under the Soviet Academy of Sciences.

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[15] Ibid.

[16] Kruger, Paul and Otte, Carel., op. cit., p. 36.

[17] Wehlange, Edward. Iceland's Geothermal Story. Geothermal Energy. v. 2, n. 3, March 1974. p. 10.

[18] Kruger, Paul and Otte, Carel., op. cit., p. 37.

At the present time, geothermal resources are considered as a new branch of the national economy. The Ministry of the Gas Industry has established several organizations and prospecting expeditions for the development of geothermal resources in general and of steam resources in particular. The Ministry's goal for the current Five Year Plan (1971–1975) is to drill over 10,000 meters of geothermal test wells.[19]

Since 1967, the utilization of geothermal water in the Soviet Union has increased markedly. The U.S.S.R. is now the world's largest user of geothermal energy for heating purposes. Several towns and industries use thermal water for heating and for growing vegetables in greenhouses. Geothermal water is also used for refrigeration, for thawing of frozen soils, and for swimming pools and baths. Russia's first geothermal electric power station was constructed in Paratunka on the Kamchatka peninsula located in for eastern Russia just below the Russian Arctic. It's capacity is 29 megawatts, produced from a steam-hot water mixture and it is the first station in the world to utilize recycled Freon.

It has been estimated that the geothermal resources of the Soviet Union have a capacity of 22 million cubic meters of hot water and 430,000 tons of steam daily. If fully utilized this energy resource is projected to save about 40 million tons of conventional fuel annually. The annual output set for 1975 is the production of about 15 million cubic meters of hot water and 470,000 tons of steam.[20] The total consumption of geothermal energy for space heating in the U.S.S.R. is believed to be the equivalent of one million tons of the oil per year.[21]

One of the world's largest reservoirs of hot water, extending over an area of about three million square kilometers, is located in western Siberia.[22]

The enormous artesian basin stretches to the Urals in the west, the Sayany Mountains in the southeast, the Kazakhstan steppes in the south. and to the Arctic Circle in the North. It is known as the West Siberian Plain. The temperature of the water, usually found at depths below two kilometers, varies from 40 to 60 degrees to as much as 160 degrees centigrade in deeper portions of the basin. The waters contain from 10 to 80 grams of various salts per liter.[23] The West Siberian Plain is not a volcanic region and apparently has no natural hot springs. In fact, only 140 thermal springs are reported to exist in the entire U.S.S.R.[24] The hot artesian waters are used for injection into petroleum reservoirs to enhance oil recovery by waterflooding. They are also used for therapeutic purposes, providing hot mineral water baths in the numerous spas and health centers of Western Siberia. Space heating systems for buildings and greenhouses utilizing geothermal waters are being planned and built in several western Siberian towns. It may also be possible to extract minerals from the thermal waters. In the future, Siberian geothermal waters are expected to become a source of electric power using somewhat the same conversion system as the plant at Paratunka.

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[19] Soviet Geothermal Electric Power Engineering. Advanced Research Projects Agency, Department of Defense. Report 2, December 1972, p. 11.

[20] Ibid.

[21] Kruger, Paul, and Otte, Carel, op. cit., p. 43.

[22] Ibid.

[23] Ryabov, Yuri. Siberia's Hidden Heating System. New Scientist, v. 37, n. 590, 28, March 1968, p. 689.

[24] Warning, G. A., op. cit.

In several areas of northeastern Siberia, geothermal heating projects are also in the planning and construction stages.

Geothermal development in the Soviet Union depends upon the location of the source, accessibility and condition of roads, overall economic development of the region in question, and the availability of other types of energy resources. Based on hydrological, geological, and geothermal characteristics, the Soviet Union is subdivided into nine regions having different priorities and prospects for geothermal resource development.[25]

SUMMARY AND COMPARISONS

Alaska, with its numerous volcanic regions and thermal springs, has good geological potential for geothermal deposits, but has little in the way of actual geothermal development. The Aleutian Chain and the Seward Peninsula, both containing regions classified as "known geothermal resources areas," may have significant potential for geothermal generation of electricity and for geothermal space heating and horticulture.

Arctic Canada, Greenland, and the Scandinavian countries appear in general to lack the geologic potential for geothermal development. Iceland, however, is located on the volcanically active mid-Atlantic ridge and has long utilized geothermal energy for space heating and for horticulture. Its Capital, Reykjavik, is almost totally heated by geothermal waters at a cost estimated to be a fraction of that of fuel oil heating. Geothermal waters in Iceland are also used to generate electric power and for various industrial purposes. Iceland plans continued expansion of its considerable utilization of geothermal energy.

The Soviet Union is the world leader in the use of geothermal energy for heating purposes. Several towns and industries use geothermal waters for heating and for horticulture. Geothermal waters are also used for the generation of electricity for refrigeration, for thawing frozen soils, and for swimming pools and baths. The total consumption of geothermal energy for space heating alone in the U.S.S.R. is believed to be the equivalent of one million tons of fuel oil per year. There is great potential for geothermal resources development in the Soviet Arctic. One of the world's largest reservoirs of hot water, extending over an area of about three million square kilometers, is located in western Siberia. These thermal waters are being used for space heating, industrial purposes, and health spas, and will be used in the future for the production of electric power. In several areas of northeastern Siberia, geothermal heating projects are in the planning and construction stages. At the present time, geothermal resource development is being pursued as a new branch of the Soviet national economy under the Ministry of the Gas Industry. Actual geothermal development priorities depend upon geologic potential, accessibility, of the resource, overall economic development of the region, and the availability of other types of energy resources.

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[25] Soviet Geothermal Electric Power Engineering, op. cit., p. 23.

OTHER ENERGY RESOURCES

Oil Shale

ALASKA

Marine oil shale deposits are found in several areas throughout Alaska. However, for the most part these shales (which are mostly Mesozoic in age) have been little studied or evaluated. Known resources are small although possible inferred resources are estimated to contain within an order of magnitude of 250 billion barrels oil equivalent in deposits yielding more than 25 gallons per ton and perhaps more than 200 billion barrels in deposits yielding 10 to 25 gallons per ton.[1] Deposits that yield five to ten gallons per ton are presumed also to be large.

Two major oil shale regions have been identified in Alaska, along the Brooks Range in northern Alaska and along the Nation River in eastern Alaska. In the Shublik Formation, in the northern foothills of the Brooks Range, black papery oil shale is intermittently exposed in a belt over 480 kilometers (300 miles) long. A few selected samples have yielded 25 gallons of oil per ton. Samples of high-grade oil shale in the Tiglukpuk Formation along the northwestern foothills of the Brooks Range have yielded 30 to 140 gallons of oil per ton. This deposit of high-grade shale is inferred to contain within an order of magnitude of 50 billion barrels oil equivalent. Other oil shales are found in the Brooks Range in the Seabee Formation in a zone extending 130 to 160 kilometers (80 to 100 miles) along the northern foothills, and in an older marine shale of Mississippian age which yields about seven gallons of oil per ton.

Oil shale deposits up to 60 meters thick are exposed for 16 kilometers along the Nation River in eastern Alaska. Known recoverable resources are estimated at about two million barrels of oil equivalent from shale yielding around 30 gallons per ton. Possible inferred resources in the region from similar grade oil shale are estimated to be about 200 billion barrels.[2]

Oil shale also occurs in the Christian River basin in northern Alaska but has not been thoroughly investigated.[3] In general, Alaskan oil shale deposits have received little attention since the location of the deposits poses a major economic constraint on their development.

ARCTIC CANADA

Scattered low grade oil shale deposits are found in Arctic Canada in marine shales of Mezozoic and Paleozoic age. No specific estimates of the size or resource potential of the individual deposits are available. Random analyses of some of the marine black shale deposits have indicated low oil yields of around seven to 15 gallons of oil per ton.[4]

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[1] Duncan, D. C. and V. E. Swanson. Organic-Rich Shale of the United States and World Land Areas. U.S. Geological Survey Circular 523. Washington, 1965, p. 14.

[2] Ibid., p. 14

[3] U.S. Geological Survey. Synopsis of the Mineral Resources and Geology of Alaska. Bulletin 1307, Washington, D.C., 1974, p. 20.

SWEDEN

In southern Sweden, a shale oil industry developed in 1940 to provide an alternate fuel in the event of World War II. The industry reached a level of processing of over two million tons of shale per year before it was discontinued in 1966 for economic reasons. The deposits are located in three areas in the provinces of Närke, Öland, and Gotland are considered by the U.S. Geological Survey as known marginal and submarginal resources.[5] Most of these resources yield more than ten gallons per ton and contain a total of about 2.85 billion barrels oil equivalent. Some zones of these shale deposits contain substantial amounts of uranium and other metals.

ARCTIC RUSSIA

In the northeastern Siberian platform large marine oil shale deposits are reported to underlie more than 150,000 square kilometers in the Anabar, Olenek, and Lena Rivers regions. The deposits range in thickness from 18 to 85 meters. Known resources are estimated to contain about 112 billion metric tons of shale or 78 billion barrels oil equivalent. Of this the Russians consider about 22 billion tons minable, which would yield about 14 billion barrels of oil.[6] Possible inferred resources in unexplored extensions yielding 10–20 gallons of oil per ton might contain within an order of magnitude of 3.5 trillion barrels of oil equivalent.

In European Russia near 60° N. latitude, oil shale, known as kukersite, underlies broad areas of Estonia and the adjacent Leningrad region. Production began in the 1920's and is currently at the annual level of 26 million tons per year. This region contains an estimated 22 billion tons of shale of which 15 billion tons is considered, by Russian standards, rich and thick enough to mine. The estimated recoverable resources in this region, from shale yielding up to 50 gallons per ton, amount to 10 billion barrels oil equivalent. Potential shale reserves claimed by the Soviet Union total 156 billion metric tons of which "explored" reserves total 16.2 billion tons, most of which is in Estonia.

Most of the Estonian oil shale is found in thin seams at a depth of 20 to 30 meters. An increasing proportion is mined from open pits. Currently, the Estonian Shale Administration operates eight underground mines and four open pits. Total oil shale production in the U.S.S.R. reached 27 million tons in 1972[7] and is expected to have exceeded 32 million tons in 1975 with over 26 million tons coming from the Estonian deposits.[8] Long range plans call for increasing output to 50 million tons per year.

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[4] U.S.G.S. Circular 523 op. cit. p. 17.
[5] Ibid., p. 25.
[6] Ibid., p. 20.
[7] U.S. Bureau of Mines, Minerals Yearbook 1972, v. III., Washington, D.C., 1974, p. 850.
[8] The Current Digest of the Soviet Press. v. 27, n. 28, 1975, p. 21.

Over two-thirds of the extracted shale is burned at thermal electric power plants, the rest is processed into more than 40 chemical products and fuels including pipeline gas, gasoline, kerosine, fuel oil, diesel oil, lubricants, asphalt, benzene, toluene, xylene, butyl alcohol, phenols, acetone, detergents, ammonia, pesticides, herbicides, tanning agents, aniline dyes, flotation agents, solvents, plasticizers, polyesters, synthetic fibers, plastics, synthetic rubber, adhesives, paints, varnishes, ion exchange resins, sulfur, hyposulfite, electrode coke, mineral fertilizers, and pharmaceuticals. In addition part of the ash accumulated at electric power plants is used to make cement, to lime acid soils, and to manufacture wall panels.

The Russian oil shale industry has recently come under criticism from Government officials for pollution problems and "intolerable" mining losses (around 30 percent in the Estonian basin as a whole and as high as 50 percent at some mines). The deputy to the Council of Nationalities from Estonia stated:

> The methods of shale refining require serious attention. Pollution of rivers, groundwater and air by sulfur compounds, phenols, and aromatic hydrocarbons, as well as by dust, at many locations in the Estonian basin already exceeds permissible levels. The danger has arisen that some of the effluents from the mines will enter Chudskoye Lake by way of the Rannapungerya River, polluting this important body of water, which is the sole large reserve of fresh water for the cities of Tallinn, Narva, Kohtla-Jarve and others.[9]

Furthermore, in the past shale ash has been piled in enormous mounds more than 90 meters (300 feet) high around Estonian cities.

The Soviets have been trying to upgrade their oil shale industry since the early 1960's but have been making slow technical progress.[10] According to the director of the Tallinn Polytechnical Institute, "the program has been bureaucratically split into isolated enterprises, each of which operates in the least rational way." [11]

On the other hand, Resources Sciences Corporation, a subsidiary of U.S. Filter Corporation, signed an agreement with V–O Licensintorg, exporter and importer of technologies for the Soviet Union, allowing two Russian shale processing and oil recovery technologies to be licensed to U.S. industry.[12] At a symposium sponsored by Resources Sciences Corporation in Tulsa December 3, 1975, Soviet experts were available to explain their oil shale technology. Two processes called the Kivitar and the Galoter were described.[13] Participants from U.S. industry noted that the Soviet equipment appeared to be pilot-scale by U.S. standards and would not process enough oil shale to be commercially economic. Furthermore, although the numerous years of Soviet experience was a plus, the high amount of fine particle carryover (4 to 5 percent) into the shale oil from the Galoter process was disturbing. Finally despite efforts to adapt Soviet experience to U.S. conditions, it was pointed out that extra costs would likely mount up for air pollution control, waste disposal, water procurement, and the general difficulty of operating in more remote U.S. areas.

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[9] Ibid.

[10] The Oil and Gas Journal. Soviets Admit Troubles in Oil Shale. October 6, 1975, p. 42–43.

[11] Ibid., p. 43.

[12] Energy Resources Report. August 22, 1975, p. 338.

[13] Prescott, J. H. Soviet Oil-Shale Processes Offered for U.S. Licensing. Chemical Engineering, February 2, 1976, p. 66–67.

URANIUM

ALASKA

"Alaska should be considered a potential source of major quantities of uranium."[14] Considering the great size, favorable geology for uranium concentration (acid igneous rocks and their sedimentary derivatives), and the relatively unexplored areas of the state, it seems likely that important concentrations of uranium eventually will be located. Several radioactive "highs" have been mapped throughout the state, but commercial production has only resulted from one area, Bokan Mountain in southeastern Alaska. Several localities on the Seward Peninsula, particularly the Ear Mountain and Brooks Mountain areas, are known to contain high uranium values. Further exploration in these areas may uncover commercial deposits. Other promising areas for commercial uranium concentrations are the Hyder mining district, Skagway, and the Salmon Bay area all in southeastern Alaska, the Hope Creek area near Fairbanks, near Rampart on the Yukon River, the Selawik Basin region of western Alaska, and the Tyonek area in southwestern Alaska. Phosphate beds in the northern foothills of the Brooks Range contain low grade uranium which could be produced as a byproduct at some future time.

Commercial production began in 1957 and continued through 1964 in the Bokan Mountain area near Kendrick Bay on the southeastern part of Prince of Wales Island in southeastern Alaska. During this time approximately 39,000 tons of ore were produced averaging 1.0 percent U_3O_8.[15] More than half this tonnage was mined by open pit methods. The mine closed in 1964 but was reopened under new ownership a few years later to meet an increasing demand for uranium. Production during the 1971 season reached 55,000 tons of highgrade uranium bearing ore. The mine is owned by the Newmont Mining Corporation and the ore is shipped by barge to the Dawn Mining Company's uranium concentrating plant at Ford, Washington.

ARCTIC CANADA

Canada's uranium resources are large, currently amounting to approximately one-fifth of the world's total. Most of Canada's uranium resources and about 85 percent of its production comes from two localities in Ontario, the Elliot Lake and Agnew Lake areas. The uranium resources in the Canadian Arctic are primarily in vein and replacement type deposits in the areas of Port Radium-Marian River, Baker Lake-Amer Lake, and Great Slave Lake-Nonacho Lake in the Northwest Territories. Similar deposits are being exploited in northern Saskatchewan in the Uranium City area, while the Carswell Dome and the Wollaston Lake Belt account for the remaining 15 percent of Canada's uranium production.

A considerable effort has been expended in exploration of radioactive quartz-pebble conglomerates in the Northwest Territories equivalent in age to the uranium-bearing Ontario conglomerates, but no economic deposits have been found. Subeconomic uranium-bearing pegmatites are also found in the Northwest Territories. The last production reported from the Northwest Territories was 9,231,698 kilograms of pitchblende in 1960. Canada's crown corporation, Eldorado Nuclear Ltd., reported total reserves at the Great Bear Lake and Uranium City areas of 2,803,200 tons containing 0.22 percent U_3O_8 at the end of 1972.[16]

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[14] Eakins, G. R. Uranium in Alaska. Geological Report No. 38, Division of Mines and Geology, Dept. of Natural Resources, State of Alaska, May, 1969, p. 4.

[15] Ibid., p. 6.

GREENLAND

In general, the Danish Government plans to grant mineral rights in Greenland to private enterprise, but it has reserved uranium for the state. At Kvanefjeld in south Greenland, near Julianehab, the Danish Government has set aside an area containing low-grade uranium reserve for the Danish Atomic Energy Commission. The area contains intrusive alkaline igneous rocks locally enriched in uranium and thorium. The Kvane Mountain deposit is relatively low grade, at 320 grams per metric ton uranium content (0.03 percent), but the site is easily accessible, could be worked by open pit methods, and other minerals could be extracted. A report by the Nuclear Energy Agency of the Organization for Economic Cooperation and Development (OECD) estimates that about 250,000 tons of uranium in ore averaging 0.02 percent could be economically recovered from this deposit.[17] The Danish Atomic Energy Commission estimates there is sufficient ore for about 16 years' production at an output of about 400 tons per year uranium.[18] The Commission has asked the Ministry for Greenland to plan future development of the deposit. Total potentially recoverable resources are estimated by the Danish Atomic Energy Commission at 32 million metric tons of uranium ore.

NORWAY

Norway has no known economically recoverable uranium deposits. Uranium prospecting in Norway has been limited to about one-half man-year annually. However, recent discoveries in Sweden near the Norweigian border will likely renew interest.

SWEDEN

Sweden has large resources of low grade uranium ore, averaging about 0.03 percent uranium in dark, bituminous shales. These shales are widely distributed in the southern part of the country and are found in the mountain chain to the west. In 1973 reasonably assured resources at the price range of $10–15 per pound U_3O_8 were reported at 270,000 tons uranium (350,000 tons U_3O_8) and estimated additional resources at 40,000 tons uranium (52,000 tons U_3O_8).[19] The Geological Survey of Sweden has increased its program for uranium prospecting over the last few years and several promising prospects have been found in Precambrian rocks of the Fenno-Scandinavian Shield.

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[16] Folinsbee, R. E. and A. P. Leech. Uranium and Thorium: Future Energy Sources. In Symposium on Energy Resources, Royal Society of Canada, Ottawa, 1973, pp. 81–97.

[17] OECD Nuclear Agency. Uranium Resources. Production and Demand. Paris. 1973. p. 45.

[18] Prast, W. C. Greenland—Mines and Prospects. Mining Magazine, January 1973, p. 30.

[19] OECD Nuclear Energy Agency, op. cit., p. 71.

Uranium deposits have been located in the Arjeplog area of Norrbotten County, but are not yet considered to be economically exploitable. Uranium mineralization has also been reported near Storsjo in west-central Sweden.

AB Atomenergi has been experimenting with uranium extraction for several years at a pilot plant at Ranstad in south-central Sweden. Thus far the company has not been successful in lowering the cost of extraction to a commercially economic level. The high cost, limited development and concern for landscape preservation will likely confine these resources to supplying Sweden's domestic uranium requirements. Expansion is planned at the Ranstad mine and mill to increase production about nine times present capacity over a seven year period. Production was reported at 70 metric tons U_3O_8 in 1972 which is less than half the plant's capacity of 155 tons U_3O_8.[20]

FINLAND

Uranium exploration has intensified in Finland with the work being carried out both by private companies and the Geological Survey and supported by the Finish Atomic Energy Agency. In 1971 a special Government committee was formed to coordinate prospecting activities. Two discoveries have been made recently in Precambrian sedimentary formations at Kolari in northern Finland and Paltamo in eastern Finland. The reasonably assured resources of these two deposits are estimated at 1,300 tons uranium (1,700 tons U_3O_8) at a production cost in 1973 of $10 to $15 per pound U_3O_8.[21] No decision has been made to develop these deposits and they would be considered for domestic use only. Uranium and thorium have been found in a large carbonatite deposit at several locations in northern Finland. However, these are no estimates yet on the resource potential of this deposit. Subeconomic uranium deposits have been known for some time in southern and eastern Finland in the parishes of Perno, Askola, and Eno. From 1958 to 1961, a private company, Atomienegia Oy, carried out uranium mining and ore dressing experiments on a pilot plant scale near Joensuu, North Carelia, in eastern Finland. There has been no uranium production in Finland since then.

ARCTIC RUSSIA

Although statistics are not published on Soviet uranium resources, several deposits are known. Among the major deposits are the Min-Kush, Mayli-Say, and Tabashar areas of central Asia, Zheltyye Vody in the Ukraine, and Sillimde in northern Estonia. The Estonian deposits, near 60° N latitude, presumably are similar to the organic shale deposits in southern Sweden. The Siberian uranium resources are considered large.[22] Some indication that Soviet uranium production is in excess of its own expanding power needs or ability to use it came on October 6. 1973 when the U.S.S.R. entered the Western World's uranium market with a 700 ton sale of enriched uranium through the European Economic Community (EEC) to West German utilities.

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[20] U.S. Bureau of Mines. Minerals Yearbook, 1972. v. III, Dept. of Interior, Washington, D.C., 1974, p. 754.

[21] OECD Nuclear Energy Agency, op. cit., p. 45.

[22] Slocum, M. Soviet Energy: An Internal Assessment. Technology Review, Oct./Nov. 1974, p. 23.

Several nuclear power stations are planned for the Soviet Arctic. One 880,000 kilowatt pressurized water type station is under construction on the Kola Peninsula south of Murmansk. Four small atomic power plants of 12,000 kilowatts each are planned for Bilbino in northeastern Siberia.

Nuclear power plants generated over 7.7 billion kilowatt-hours, or 0.9 percent of all Soviet electric power in 1972. Four plants are in operation with a total capacity of 1.8 million kilowatts. All existing Soviet nuclear power plants use uranium 235 for fuel.

SOLAR ENERGY

SOLAR

Even at high latitudes solar energy can be utilized effectively. While the sunlight reaching the earth's surface is less intense than at lower latitudes because of the low angle of incidence, properly inclined collectors can help to compensate for this. The daily solar insolation depends both on incidence of the radiation and the duration of daylight. Consequently, during the summer polar seasons the amount of daily solar radiation reaching the poles is actually greater than near the equator because of the longer periods of daylight. While it cannot be utilized year round, solar energy can be an important energy resource for local use during the Arctic summer months. Several methods of utilizing solar energy in northern latitudes have been investigated. One of the more promising areas of solar energy development for the north is as a supplemental heat source in buildings. Even in the summer months indoor heating is often necessary in the Arctic. Increasing fuel costs make solar augmentation of heat more attractive. One plan considers a flat, greenhouse type photothermal converter coupled with a conventional heating system and heat storage tank as being cost effective now in some areas above 60° N.[23] Technological improvements and increases in production could be expected to lower the costs of solar heating further.

Another means of utilizing solar energy in the north is through the extraction of ground heat by a heat pump system. Ground heat pump systems have been developed in Denmark and have been installed in several new homes there. Two engineers at the University of Alaska have calculated that ground heat pump systems could save 60 to 80 percent on home heating bills in the Fairbanks area and would amortize their higher cost in a few years.[24] Ground heat pump systems work like air conditioning systems in reverse. A refrigerant is allowed to expand in coils buried in the ground where it takes on heat which is released when the refrigerant is compressed again inside the house. The heat collected from the ground is stored solar energy. Consequently, in high latitudes heat extracted during the winter could not be replaced until the following summer. An additional benefit of ground heat pump systems is in stabilizing the ground in areas of permafrost by keeping the permafrost frozen. By installing the ground grid around the foundation of the building, differential settling from freeze-thawing could be prevented. However, systems such as these require further research and development before firm facts and figures are available on their cost effectiveness and practical feasibility.

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[23] Mirth, R. A., The Sun Can Heat Our Home—Even in the North. Northern Engineer, v. 6, no. 3, 1974. pp. 3–10.

[24] Stenbaek-Nielsen, H. C. and L. R. Sweet. Heating with Ground Heat: An Energy Saving Method for Home Heating. Northern Engineer, v. 7, n. 1, 1975, p. 20–25.

WIND

The basic technology for harnessing wind power was developed over 60 years ago. Improvements have gradually been made toward larger scale applications. One system claimed to be cost effective has been conceptually designed for offshore New England to produce hydrogen from wind-generated electricity. The annual power potential of this system is judged to be 159 billion kilowatt hours.[25] By comparison, along the Aleutian Chain a wind energy system 2,000 kilometers long with transects each 66 kilometers long, spaced at 96-kilometer intervals, between 100 meter contours could be developed with a potential annual power production of 402 billion kilowatt-hours.[26]

This hypothetical system would liquefy hydrogen for transport to California by tanker. However, while there is this large potential for wind energy development in the Aleutians, the cost effectiveness remains to be proven. Further research and development in this area would be needed before it can be conclusively determined whether or not a wind energy system such as this would be economically practical.

Accumulation or storage of wind energy is a problem since generation depends upon when the wind is blowing, and if it is calm a back up energy system must be available. In countries such as Norway and Sweden which have large hydroelectric systems this problem is less critical. Normally, it is the mass of water rather than generator output that limits hydroelectric installations. Water can be stored until calm days and then used. The Swedish State Power Board has found that in 1990, wind generators with a total output of as much as 5,000 megawatts might be incorporated in the national system without any special provisions for storage because of the large hydropower capacity.[27] Every power system has some capacity to absorb the irregularity of wind plants, but thermoelectric plants have somewhat less flexibility.

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[25] National Science Foundation. Solar Energy as a National Energy Resource. NSF/NASA Solar Energy Panel. NSF/RA/N-73-001, Washington, D.C., 1972, p. 68.

[26] Ibid. p. 69.

[27] Engstrom, S. Renewable Energy Resources: Wind Energy From a Swedish Viewpoint. Ambio, v. 4, n. 2, 1975, p. 75–79.

INTERNATIONAL RELATIONS

LAND AREAS

Eight nations have sovereignty over territory in the Arctic. These are the United States, Canada, Denmark (Greenland), Norway, and the Soviet Union which border the Arctic Ocean, plus Iceland, Finland, and Sweden. In contrast to Antarctica, the Arctic is inhabited, although for the most part very sparsely. Consequently, there has been a longer interest in sovereignty in the Arctic and territorial disputes over all land areas appear now to be resolved. One of the more interesting and unusual settlements of territorial claims was made by the Paris Treaty of February 9. 1920 concerning Svalbard in which Norway was awarded sovereignty over Svalbard (Spitsbergen) but prohibited from establishing military bases and fortifications there. In addition all contracting parties to the treaty were granted equal rights to exploit the resources of Svalbard, subject to the rules and regulations set by Norway.

OCEAN AREAS AND U.N. LAW OF THE SEA CONFERENCES

In two separate conventions the First U.N. Conference on Law of the Sea in 1958 set limits for the territorial sea and contiguous zone, but did not precisely define the extent of the continental shelf or seabed subject to a coastal states exploitation. The Convention on the territorial Sea and the Contiguous Zone did not define the limits of the territorial sea but established a limit of 12 miles for the combination of territorial sea and contiguous zone. The Conventon on the Continental Shelf states:

> For the purposes of these articles, the term "continental shelf" is used as referring (a) to the seabed and subsoil of the submarine areas adjacent to the coast but outside the area of the territorial sea, to a depth of 200 meters or, beyond that limit, to where the depth of the superjacent waters admits of the exploitation of the natural resources of the said areas; (b) to the seabed and subsoil of similar submarine areas adjacent to the coasts of islands.
>
> The coastal State exercises over the continental shelf sovereign rights for the purpose of exploring it and exploiting its natural resources. . . .
>
> The rights of the coastal state over the continental shelf do not affect the legal status of the superjacent waters as high seas, or that of the airspace above those waters.[1]

At the time when these conventions were drafted, the likelihood of exploiting the shelf and seabed areas beyond 200 meters depth seemed remote. However, in view of recent developments in marine technology, the possibility is no longer remote. Consequently, one of the major issues being addressed in the Third U.N. Conference on Law of the Sea now underway is the establishment of more precise limits to the seabed areas of coastal state resource ownership.

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[1] 15 UST 471 . TIAS 5578, articles 1, 2, and 3.

One further provision of the Convention on the Continental Shelf is particularly relevant to territorial conflicts that have developed in the Arctic. Article 6 states:

> Where the same continental shelf is adjacent to the territories of two adjacent states, the boundary of the continental shelf shall be determined by agreement between them. In the absence of agreement, and unless another boundary line is justified by special circumstances, the boundary shall be determined by application of the principle of equidistance from the nearest points of the baselines from which the breadth of the territorial sea of each state is measured.[2]

THE SECTOR PRINCIPLE

While disputes over land areas appear to be resolved, questions of sovereignty over Arctic seas and shelf areas still remain. Under current international law the northern ocean areas are part of the high seas belonging to no one. On the other hand, the question of how far offshore territorial limits and the right to exploit seabed resources extend is not resolved. Both the Soviet Union and Canada assert the sector principle. This principle simply states that each country bordering the Arctic Ocean should draw a line from its easternmost and westernmost boundaries to the North Pole. The triangular sector thus formed in the Arctic delineates sovereign boundaries. When these claims were initially advanced both countries were primarily concerned with preventing foreign colonization of both the discovered and undiscovered land areas. However, Canada now claims sovereignty on the basis of exploration, occupancy, and administration, of all land areas except Greenland north of the mainland of North America between longitude 62° W and 141° W. Similarly, the islands that lie within the Soviet sector are not disputed because of exploration, occupancy, and administration by the Soviet Union.

In the Soviet proclamation of 1926, no claim is advanced over the waters and drifting ice within the sector between the meridians of 32° 4′ 34″ E and 168° 49′ 30″ W. Little Diomede was accepted as belonging to the United States and Svalbard as belonging to Norway. In 1928 and again in 1950 the Soviet press advanced claims to the open polar seas, including drifting ice, but the official Soviet position has not been made clear. While the Soviet Union has not demonstrated a territorial interest in the Soviet sector of the Arctic Ocean with regard to prohibiting excursions of foreign vessels and aircraft, there are indications to some observers that the Soviet Union regards the maritime area bordererd by its mainland and island territories in the Arctic Ocean as "Soviet inland seas." [3] In a separate claim the Soviet Union has defined its territorial waters as bounded by a 12-mile limit including islands. On the other hand, as has been stated, "It would be unrealistic to suppose that she [the Soviet Union] would not demonstrate a proprietary interest in the area defined in the decree of 1926 should she see fit." [4]

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[2] Ibid., article 6

[3] Huitfeldt, Tonne. A Strategic Perspective on the Arctic. Cooperation and Conflict, v. 9, 1974, p. 83–99.

[4] Sater, John E. The Arctic Basin, revised edition. The Arctic Institute of North America, Washington, D.C., 1969, p. 10.

CONTINENTAL SHELF BOUNDARY DISPUTE BETWEEN NORWAY AND THE SOVIET UNION

Not only is the sector principle contested in its extension to the pole, but in the region between the Soviet Union and Norway its application conflicts with the principle of equidistance which has a more solid basis in international law. Both Norway and the Soviet Union claim the shelf area between Kvitoya and the Kola Peninsula, an area of about 155,000 square kilometers or equal to half of Norway's total territory on land. The line of equidistance would form an irregular boundary, much more to Norway's advantage, eastward of the sector line (even allowing for an eastward jog in the sector line around Spitsbergen).

The Soviet insistance on the sector line apparently reflects strategic interests as well as interest in seabed resources. Murmansk, the Kremlin's only more or less ice-free port on the Arctic Ocean, is the primary base of the northern fleet. At the beginning of this century, the principle bases of the Soviet Navy were in the Baltic and the Black Sea. However, in recent years the Soviets have systematically expanded their naval facilities on the Kola Peninsula so that now their largest fleet, containing some 70 percent of the Soviet missile-armed submarines, is reportedly stationed there.[5] Consequently, for both defensive and offensive purposes the Soviets are concerned that they control the area near Murmansk and their access to the open sea through the Spitsbergen Strait.

Development of seabed resources from the shelf around Spitsbergen is also a point of contention between Norway and the U.S.S.R. Some of the provisions of the Treaty concerning Svalbard apply to Svalbard's territorial waters but no mention is made in the treaty concerning the continental shelf around Svalbard. In the Norwegian view, the continental shelf around Svalbard is part of the Norwegian continental shelf, which stretches from the coast of Norway out to the point where it drops off north of Svalbard. The Soviet Union maintains, on the other hand, that the provisions of the Svalbard Treaty must be carried out onto the shelf around the archipelago, and that the parties to the treaty must also have equal rights with regard to exploration and exploitation of possible resources on the shelf.

There are two hypotheses about the Soviet concern for resource development on the Svalbard shelf. According to one view because the archipelago is so strategically located, the Soviets want to control it directly. The other view suggests that perhaps the Soviets would prefer to see Norway's position upheld, thus keeping other countries out, and then seek to influence Norway. The possibility that pressure may be exerted by the Soviets was suggested by the Soviet decision to test missiles in the Barents Sea north of Murmansk just prior to talks with Norway last fall over jurisdiction of the shelf areas.

The Soviet Union already maintains a large presence on Svalbard (the population is reported to consist of 1,000 Norwegians and 2,000

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[5] Kamer, Hansrudolf. Norway and the USSR Square Off in the Arctic. Swiss Review of World Affairs, v. 24, n. 6, Sept. 1974, p. 4–7.

Russians) for the stated purpose of mining coal. Since no other countries have been attracted to the resources of Svalbard for about 50 years, the Soviets would probably not have brought up the shelf question if it hadn't been for the offshore oil and gas discoveries in the North Sea between Norway and Great Britain. Geological and geophysical evidence indicates that the Barents Sea is also a potential oil and gas province. One concern of the Soviets is the possible military uses to which offshore drilling and production platforms can be put. Experts disagree as to whether installations on such structures are more effective than the already developed electronic devices in the water or on the sea bottom now used to monitor fleet movements. On the other hand the presence of drilling platforms can be politically exploited and interpreted as a provocation.

OTHER CONTINENTIAL SHELF BOUNDARY DISPUTES

The Soviet Union is also engaged in a dispute with Sweden over shelf areas in the Baltic Sea. Recent oil strikes by Sweden on and near the Swedish island of Gotland have prompted the Soviets to renew their boundary claims that the Baltic should be divided midway between the mainland of each country. Sweden maintains that the boundary should lie midway between Gotland and the Soviet mainland. A similar situation exists between Sweden and Poland regarding Gotland.

SUMMARY

The greater part of the Arctic is a virtual desert with the precipitation that does fall consisting of small, dry, hard snow particles which are easily redistributed by the wind, producing blowing-snow storms. Based on annual temperature curves, the Arctic can be divided into maritime, coastal, and continental type climates. The air temperature over the Arctic Ocean ranges from around the freezing point in June, July, and August to around −34 degrees centigrade during the winter with rather minor fluctuations. The coastal climate is somewhat similar to the maritime climate, the main difference being a warmer summer season with temperature maximums in July. However, the mean summer temperature in the coastal areas remains below 10 degrees centigrade resulting in a summer season which compares to the spring and fall of the continental climate. The Arctic continental climate is characterized by very low winter temperatures with a very pronounced summer maximum. The annual range of continental mean temperatures may be as much as 72 degrees centigrade.

That the Arctic is a vast storehouse of energy has long been recognized, but only recently, with the partial depletion of energy resources at lower latitudes and the rising world demand for energy, has the exploitation of Arctic energy resources been undertaken on a large scale. This has been the case with such scarce energy resources as oil and natural gas; but the Arctic, in the future, could be exploited for other energy resources as well.

With the discovery of the large hydrocarbon reserves at Prudhoe Bay, it became apparent that the petroleum potential of the State of Alaska is very great. The U.S. Geological Survey estimated in 1975 that the hydrocarbon potential of Alaska included known reserves of 10.107 billion barrels of oil and 31.867 trillion cubic feet of natural gas. Undiscovered recoverable resources were estimated by the Survey at six to 19 billion barrels of oil and 16 to 57 trillion cubic feet of gas onshore, and three to 31 billion barrels of oil and eight to 80 trillion cubic feet of gas offshore. The United States is exercising caution in the exploitation of its Alaskan oil and gas deposits because of environmental considerations.

Arctic Canada is thought to contain potential oil reserves of 51 billion barrels and potential gas reserves of 413 trillion cubic feet. Known gas reserves are given at 21.2 to 27.9 trillion cubic feet, slightly less than for Alaska. The Canadian Government has recently began a policy of self-reliance in oil and gas in order to attempt to reduce its dependence on foreign oil. The policy includes measures to increase domestic supplies and to encourage conservation. The plan would allow energy prices to rise to provide the income needed by the petroleum industry to increase exploration and government exploration and development spending in the northern frontier would be doubled during the next three years. An indicator of Canadian determination to exploit its Arctic regions for needed energy supplies was the recent governmental decision to allow exploratory drilling in the Beaufort Sea in spite of the environmental concerns of local groups and of the United States government.

It is apparent after a decade of drilling, that the North Sea is one of the major petroleum provinces of the World. The Norwegian Petroleum Directorate has estimated, based on the volume of sedimentary rock and compared to the estimated potential of the shelf south of 62 degrees north, that its Arctic shelves could contain as much as 125 to 150 billion barrels of oil and 725 to 870 trillion cubic feet of natural gas. The first exploratory drilling north of 62 degrees is planned for the spring of 1977. It will be undertaken in the region where the North Sea becomes the Norwegian Sea. The Norwegian Government has picked the two most promising local areas and has indicated that concessions will be granted in these areas in time for drilling in 1977.

In 1974, the Soviet Union overtook the United States to become the world's major oil producer. About 95 percent of the U.S.S.R. net oil production gain in 1974 came from Western Siberia. The Soviet Arctic contains vast oil and natural gas resources with known oil reserves of 88.5 billion barrels and known gas reserves of 1,004 to 1,284 trillion cubic feet. Potential Soviet Arctic resources have been estimated at 410(+) billion barrels of oil and 2,588(+) trillion cubic feet of gas.

The Soviet government is committed to the rapid development and exploitation of the West Siberian oil and gas region. Of second, but almost equal, priority is the development and exploitation of the Pechora Basin. Third in priority among the Arctic regions is the East Siberian Province. Foreign capital and technology may be the key factor in the development of Siberian oil and gas as the Soviets are raising their production goals beyond those that have already been judged overambitious by Western experts. The Soviets have however, established contact with Western oil companies and banks that could provide need technology and financing to increase Soviet Arctic oil and gas development.

The oil and gas deposits in the Polar regions are very great. Known reserves of oil in Polar areas are almost three times larger than those in the United States. Natural gas reserves in the Polar regions appear even more significant almost equaling the known gas reserves of the entire non-Communist world.

Oil and gas exploitation on a large scale is now underway in Arctic regions. Such activities will, no doubt, increase in the future as oil and gas resources become more and more depleted in the temperate latitudes. Thus, the technologies associated with Polar oil and gas operations and transportation can be expected to undergo continuing research and development and utilization.

Coal is found in many parts of Alaska ranging from small isolated occurrences to very extensive fields. These resources have been conservatively estimated at more than 130 billion tons (consisting of more than 19 billion tons of bituminous coal and nearly 111 billion tons of subbituminous coal and lignite). Of these resources, an estimated one-half may be recoverable by present mining methods. The ultimate exploitation of these immense coal resources will depend upon the development of markets to which transportation costs will be competitive with other sources of supply. Transportation from the northern fields would entail either land shipment to an ice-free port in the more southerly section of Alaska or year around ice breaking service in a northern location where a port could be developed.

Coal is not presently included among the economically significant energy resources of Arctic Canada although a large deposit is known in northwestern Canada near the Arctic coast. The shield areas of the Canadian Arctic, Greenland, Scandinavia, and the Soviet Arctic are not geologically favorable for coal formation. Minor coal deposits have been mined in sedimentary basins in Greenland and Scandinavia, and coal is produced from Spitsbergen by both Russians and Norwegians. However, there is wide speculation that the Russian interest in Spitsbergen is less for economic resource exploitation than for maintaining a presence on the strategic island.

The coal resources in the Soviet Arctic are estimated at 3,715 billion tons of which 262 billion tons are in the Pechora Basin in the European Russian Arctic and the rest in the Siberian Arctic. In the Siberian Arctic, the northern part of the Lena Basin is estimated to contain 2,647 billion tons, the Taymyr Basin 584 billion tons, and the Yenisey or Tungussk Region 222 billion tons. Approximately 85 percent of the Soviet Union's "possible reserves" of coal are in the northern Siberian regions. Economically minable reserves in the Soviet Arctic are estimated at 24 billion metric tons, most of which is in the Pechora Basin. In the face of the dwindling heating capacity of coal produced in European Russia, a major incentive for the Soviets to develop coal resources in inaccessible, inhospitable Siberian regions far from major consuming centers is to gain needed high quality coking coal for industrial use. As with oil and gas, the Soviets are seeking technology and financing from the non-Communist world to develop their Siberian coal deposits.

Most Arctic areas have large undeveloped hydroelectric power potential. The potential average annual generation for Alaska is about 173 billion kilowatt-hours from a potential installed capacity of 32.6 million kilowatts. Alaska contains about one fourth of the total potential hydroelectric power resources of the United States. Less than one third of one percent of Alaska's potential hydroelectric power resources have been developed. Very little of the potential hydroelectric power resources of Arctic Canada have been developed. The undeveloped hydroelectric power resources of Arctic Canada are estimated at over nine million kilowatts. Iceland has also developed only a small fraction of an estimated potential annual generation of 35 million kilowatt hours.

In the past, lacking other energy resources, the Scandinavian countries have placed greater emphasis on developing their hydroelectric power resources. Norway has an estimated hydropower potential of about 15 million kilowatts and Sweden has an estimated developable potential of 20 million kilowatts with a potential annual generation of 85 billion kilowatt hours. Approximately half of Sweden's potential hydropower resources are being utilized. The Finnish Arctic has a large potential for the generation of hydroelectric power and hydroelectric power is one of the main sources of energy for Finland.

Although the hydroelectric power potential of the northward flowing rivers in the Soviet Arctic is immense, most of the resource potential is on the downstream portion of rivers, near the Arctic Ocean, far from where the power would be needed. Environmental concerns have also contributed to the postponement of ambitious plans to develop large hydroelectric power resources on rivers in the Siberian Arctic that would lead to flooding of vast lowland areas. Consequently, there has been relatively little hydroelectric development in the Soviet Arctic with the exception of the Kola Peninsula where hydroelectric plants generate more than 4.2 billion kilowatt hours. An additional capacity of 0.8 million kilowatts is installed around the White Sea and 0.4 million kilowatts is located in the Norilsk mining area. The diamond mining areas of Aykhal and Mirnyy in central Siberia are also served by a 0.3 million kilowatt hydroelectric plant. Soviet hydroelectric turbogenerators are competitive in the Western market. The Soviet Union claims to have a tidal power potential of 210 billion kilowatt-hours per year and boasts of the world's only tidal power plant operating in the Arctic.

Alaska has the geological potential for geothermal deposits, but has little actual geothermal development. The Aleutian Chain and the Seward Peninsula both contain regions classified by the U.S. Geological Survey as "known geothermal resources areas" and thus may have significant potential for geothermal generation of electricity and for geothermal space heating and horticulture.

Arctic Canada, Greenland, and the Scandinavian countries appear to have little geological potential for geothermal development. Iceland, however, is located on the volcanically active mid-Atlantic ridge and has long utilized geothermal energy for space heating and horticulture. Reykjavik, the capital of Iceland, is almost totally heated by geothermal waters at a cost that is estimated to be a fraction of fuel oil heating. Iceland geothermal waters are also used to generate electric power for various industrial purpoeses. The Icelandic government plans continued expansion of its considerable current utilization of geothermal energy.

The Soviet Union is the world leader in the use of geothermal energy for heating purposes. Several towns and industries use geothermal waters for space heating and for horticulture. Geothermal waters are also used for the generation of electricity, for refrigeration, for thawing frozen soils, and for swimming pools and hot baths. In the U.S.S.R the total consumption of geothermal energy for space heating alone is believed to be the equivalent of one million tons of fuel per year. There is great potential for the development of geothermal resources in the Soviet Arctic. Western Siberia contains one of the world's largest reservoirs of hot water extending over an area believed to be about three million square kilometers. These thermal waters are being utilized for space heating, industrial purposes, and health spas. Future plans call for development of electric power from the Siberian geothermal resource. Specific geothermal priorities in the Soviet Union depend upon geologic potential, accessibility of the resource, overall economic development of the region, and the availability of other types of energy resources. At the present time, geothermal resource development is actively being pursued as a new branch of the Soviet national economy under the Ministry of the Gas Industry.

Known oil shale resources in Alaska are small although possible inferred resources are estimated to contain 250 billion barrels of oil equivalent in deposits yielding more than 25 gallons per ton and more than 200 billion barrels in deposits yielding 10 to 25 gallons per ton. Known resources in the northeastern Siberian platform are estimated to contain 78 billion barrels of oil equivalent and possible inferred resources might contain around 3.5 trillion barrels of oil equivalent in deposits yielding 10 to 20 gallons of oil per ton.

Uranium has been found in several Arctic areas but potential resource estimates are sketchy. Large scale power production schemes from other energy sources such as solar or wind are still in the speculative or design stage.

Onshore territorial conflicts have been resolved in the Arctic although there is still dispute over claims to offshore continental shelf areas. At the present time, the major conflict is between Norway and the Soviet Union over the shelf area north of Murmansk and the shelf in the vicinity of Svalbard. From the Russian view, the interest is both potentially economic and currently strategic.

APPENDIX I

The Antarctic Treaty[1]

Signed at Washington December 1, 1959; Ratification advised by the Senate August 10, 1960; Ratified by the President August 18, 1960; Ratification deposited at Washington August 18, 1960; Proclaimed by the President June 23, 1961; Entered into force June 23, 1961.

By the President of the United States of America

A PROCLAMATION

Whereas the Antarctic Treaty was signed at Washington on December 1, 1959 by the respective plenipotentiaries of the United States of America, Argentina, Australia, Belgium, Chile, the French Republic, Japan, New Zealand, Norway, the Union of South Africa, the Union of Soviet Socialist Republics, the United Kingdom of Great Britain and Northern Ireland;

Whereas the text of the said Treaty, in the English, * * * languages, is word for word as follows:

The Antarctic Treaty

The Governments of Argentina, Australia, Belgium, Chile, the French Republic, Japan, New Zealand, Norway, the Union of South Africa, the Union of Soviet Socialist Republics, the United Kingdom of Great Britain and Northern Ireland, and the United States of America,

Recognizing that it is in the interest of all mankind that Antarctica shall continue forever to be used exclusively for peaceful purposes and shall not become the scene or object of international discord;

Acknowledging the substantial contributions to scientific knowledge resulting from international cooperation in scientific investigation in Antarctica;

Convinced that the establishment of a firm foundation for the continuation and development of such cooperation on the basis of freedom of scientific investigation in Antarctica as applied during the International Geophysical Year accords with the interests of science and the progress of all mankind;

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[1] Citation: 12 UST 794: TIAS 4780.

States which are parties: Argentina, Australia, Belgium, Chile, Czechoslovakia, Denmark, France. German Democratic Rep. (with declaration), Japan, Netherlands (including Surinam and Netherlands Antilles), New Zealand, Norway, Poland, Romania (with a statement), South Africa, Union of Soviet Socialist Republics, United Kingdom, United States.

Convinced also that a treaty ensuring the use of Antarctica for peaceful purposes only and the continuance of international harmony in Antarctica will further the purposes and principles embodied in the Charter of the United Nations;[2]

Have agreed as follows:

ARTICLE I

1. Antarctica shall be used for peaceful purposes only. There shall be prohibited, *inter alia*, any measures of a military nature, such as the establishment of military bases and fortifications, the carrying out of military maneuvers, as well as the testing of any type of weapons.

2. The present Treaty shall not prevent the use of military personnel or equipment for scientific research or for any other peaceful purpose.

ARTICLE II

Freedom of scientific investigation in Antarctica and cooperation toward that end, as applied during the International Geophysical Year, shall continue, subject to the provisions of the present Treaty.

ARTICLE III

1. In order to promote international cooperation in scientific investigation in Antarctica, as provided for in Article II of the present Treaty, the Contracting Parties agree that, to the greatest extent feasible and practicable:

(a) information regarding plans for scientific programs in Antarctica shall be exchanged to permit maximum economy and efficiency of operations;

(b) scientific personnel shall be exchanged in Antarctica between expeditions and stations;

(c) scientific observations and results from Antarctica shall be exchanged and made freely available.

2. In implementing this Article, every encouragement shall be given to the establishment of cooperative working relations with those Specialized Agencies of the United Nations and other international organizations having a scientific or technical interest in Antarctica.

ARTICLE IV

1. Nothing contained in the present Treaty shall be interpreted as:

(a) a renunciation by any Contracting Party of previously asserted rights of or claims to territorial sovereignty in Antarctica;

(b) a renunciation or diminution by any Contracting Party of any basis of claim to territorial sovereignty in Antarctica which it may have whether as a result of its activities or those of its nationals in Antarctica, or otherwise;

(c) prejudicing the position of any Contracting Party as regards its recognition or non-recognition of any other State's right of or claim or basis of claim to territorial sovereignty in Antarctica.

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[2] TS 993; 59 Stat. 1031.

2. No acts or activities taking place while the present Treaty is in force shall constitute a basis for asserting, supporting or denying a claim to territorial sovereignty in Antarctica or create any rights of sovereignty in Antarctica. No new claim, or enlargement of an existing claim, to territorial sovereignty in Antarctica shall be asserted while the present Treaty is in force.

ARTICLE V

1. Any nuclear explosions in Antarctica and the disposal there of radioactive waste material shall be prohibited.

2. In the event of the conclusion of international agreements concerning the use of nuclear energy, including nuclear explosions and the disposal of radioactive waste material, to which all of the Contracting Parties whose representatives are entitled to participate in the meetings provided for under Article IX are parties, the rules established under such agreements shall apply in Antarctica.

ARTICLE VI

The provisions of the present Treaty shall apply to the area south of 60° South Latitude, including all ice shelves, but nothing in the present Treaty shall prejudice or in any way affect the rights, or the exercise of the rights, of any State under international law with regard to the high seas within that area.

ARTICLE VII

1. In order to promote the objectives and ensure the observance of the provisions of the present Treaty, each Contracting Party whose representatives are entitled to participate in the meetings referred to in Article IX of the Treaty shall have the right to designate observers to carry out any inspection provided for by the present Article. Observers shall be nationals of the Contracting Parties which designate them. The names of observers shall be communicated to every other Contracting Party having the right to designate observers, and like notice shall be given of the termination of their appointment.

2. Each observer designated in accordance with the provisions of paragraph 1 of this Article shall have complete freedom of access at any time to any or all areas of Antarctica.

3. All areas of Antarctica, including all stations, installations and equipment within those areas, and all ships and aircraft at points of discharging or embarking cargoes or personnel in Antarctica, shall be open at all times to inspection by any observers designated in accordance with paragraph 1 of this Article.

4. Aerial observation may be carried out at any time over any or all areas of Antarctica by any of the Contracting Parties having the right to designate observers.

5. Each Contracting Party shall, at the time when the present Treaty enters into force for it, inform the other Contracting Parties, and thereafter shall give them notice in advance, of

(a) all expeditions to and within Antarctica, on the part of its ships or nationals, and all expeditions to Antarctica organized in or proceeding from its territory;

(b) all stations in Antarctica occupied by its nationals; and

(c) any military personnel or equipment intended to be introduced by it into Antarctica subject to the conditions prescribed in paragraph 2 of Article I of the present Treaty.

Article VIII

1. In order to facilitate the exercise of their functions under the present Treaty, and without prejudice to the respective positions of the Contracting Parties relating to jurisdiction over all other persons in Antarctica, observers designated under paragraph 1 of Article VII and scientific personnel exchanged under subparagraph 1(b) of Article III of the Treaty, and members of the staffs accompanying any such persons, shall be subject only to the jurisdiction of the Contracting Party of which they are nationals in respect of all acts or omissions occurring while they are in Antarctica for the purpose of exercising their functions.

2. Without prejudice to the provisions of paragraph 1 of this Article, and pending the adoption of measures in pursuance of subparagraph 1(e) of Article IX, the Contracting Parties concerned in any case of dispute with regard to the exercise of jurisdiction in Antarctica shall immediately consult together with a view to reaching a mutually acceptable solution.

Article IX

1. Representatives of the Contracting Parties named in the preamble to the present Treaty shall meet at the City of Canberra within two months after the date of entry into force of the Treaty, and thereafter at suitable intervals and places, for the purpose of exchanging information, consulting together on matters of common interest pertaining to Antarctica, and formulating and considering, and recommending to their Governments, measures in furtherance of the principles and objectives of the Treaty, including measures regarding:

(a) use of Antarctica for peaceful purposes only;

(b) facilitation of scientific research in Antarctica;

(c) facilitation of international scientific cooperation in Antarctica;

(d) facilitation of the exercise of the rights of inspection provided for in Article VII of the Treaty;

(e) questions relating to the exercise of jurisdiction in Antarctica;

(f) preservation and conservation of living resources in Antarctica.

2. Each Contracting Party which has become a party to the present Treaty by accession under Article XIII shall be entitled to appoint representatives to participate in the meetings referred to in paragraph 1 of the present Article. during such time as that Contracting Party demonstrates its interest in Antarctica by conducting substantial scientific research activity there, such as the establishment of a scientific station or the dispatch of a scientific expedition.

3. Reports from the observers referred to in Article VII of the present Treaty shall be transmitted to the representatives of the

Contracting Parties participating in the meetings referred to in paragraph 1 of the present Article.

4. The measures referred to in paragraph 1 of this Article shall become effective when approved by all the Contracting Parties whose representatives were entitled to participate in the meetings held to consider those measures.

5. Any or all of the rights established in the present Treaty may be exercised as from the date of entry into force of the Treaty whether or not any measures facilitating the exercise of such rights have been proposed, considered or approved as provided in this Article.

ARTICLE X

Each of the Contracting Parties undertakes to exert appropriate efforts, consistent with the Charter of the United Nations, to the end that no one engages in any activity in Antarctica contrary to the principles or purposes of the present Treaty.

ARTICLE XI

1. If any dispute arises between two or more of the Contracting Parties concerning the interpretation or application of the present Treaty, those Contracting Parties shall consult among themselves with a view to having the dispute resolved by negotiation, inquiry, mediation, conciliation, arbitration, judicial settlement or other peaceful means of their own choice.

2. Any dispute of this character not so resolved shall, with the consent, in each case, of all parties to the dispute, be referred to the International Court of Justice for settlement; but failure to reach agreement on reference to the International Court shall not absolve parties to the dispute from the responsibility of continuing to seek to resolve it by any of the various peaceful means referred to in pargaraph 1 of this Article.

ARTICLE XII

1. (a) The present Treaty may be modified or amended at any time by unanimous agreement of the Contracting Parties whose representatives are entitled to participate in the meetings provided for under Article IX. Any such modification or amendment shall enter into force when the depositary Government has received notice from all such Contracting Parties that they have ratified it.

(b) Such modification or amendment shall thereafter enter into force as to any other Contracting Party when notice of ratification by it has been received by the depositary Government. Any such Contracting Party from which no notice of ratification is received within a period of two years from the date of entry into force of the modification or amendment in accordance with the provisions of subparagraph 1(a) of this Article shall be deemed to have withdrawn from the present Treaty on the date of the expiration of such period.

2. (a) If after the expiration of thirty years from the date of entry into force of the present Treaty, any of the Contracting Parties whose representatives are entitled to participate in the meetings provided for under Article IX so requests by a communication addressed

to the depositary Government, a Conference of all the Contracting Parties shall be held as soon as practicable to review the operation of the Treaty.

(b) Any modification or amendment to the present Treaty which is approved at such a Conference by a majority of the Contracting Parties there represented, including a majority of those whose representatives are entitled to participate in the meetings provided for under Article IX, shall be communicated by the depositary Government to all the Contracting Parties immediately after the termination of the Conference and shall enter into force in accordance with the provisions of paragraph 1 of the present Article.

(c) If any such modification or amendment has not entered into force in accordance with the provisions of subparagraph 1(a) of this Article within a period of two years after the date of its communication to all the Contracting Parties, any Contracting Party may at any time after the expiration of that period give notice to the depositary Government of its withdrawel from the present Treaty; and such withdrawal shall take effect two years after the receipt of the notice by the depositary Government.

ARTICLE XIII

1. The present Treaty shall be subject to ratification by the signatory States. It shall be open for accession by any State which is a Member of the United Nations, or by any other State which may be invited to accede to the Treaty with the consent of all the Contracting Parties whose representatives are entitled to participate in the meetings provided for under Aricle IX of the Treaty.
2. Ratification of or accession to the present Treaty shall be effected by each State in accordance with its constitutional processes.
3. Instruments of ratification and instruments of accession shall be deposited with the Government of the United States of America, hereby designated as the depositary Government.
4. The depositary Government shall inform all signatory and acceding States of the date of each deposit of an instrument of ratification or accession, and the date of entry into force of the Treaty and of any modification or amendment thereto.
5. Upon the deposit of instruments of ratification by all the signatory States, the present Treaty shall enter into force for those States and for States which have deposited instruments of accession. Thereafter the Treaty shall enter into force for any acceding State upon the deposit of its instrument of accession.
6. The present Treaty shall be registered by the depositary Government pursuant to Article 102 of the Charter of the United Nations.

ARTICLE XIV

The present Treaty, done in the English, French, Russian, and Spanish languages, each version being equally authentic, shall be deposited in the archives of the Government of the United States of America, which shall transmit duly certified copies thereof to the Governments of the signatory and acceding States.

* * * * * * *

In witness whereof, the undersigned Plenipotentiaries, duly authorized, have signed the present Treaty.

Done at Washington this first day of December, one thousand nine hundred and fifty-nine.

For Argentina:
Adolfo Scilingo
F. Bello
For Australia: Howard Beale
For Belgium: Obert de Thieusies
For Chile:
Marcial Mora M
E. Gajardo V
Julio Escudero
For the French Republic: Pierre Charpentier
For Japan:
Koichiro Asakai
T. Shimoda
For New Zealand: G. D. L. White
For Norway: Paul Koht
For the Union of South Africa: Wentzel C. du Plessis
For the Union of Soviet Socialist Republics: V. Kuznetsov (Romanization)
For the United Kingdom of Great Britain and Northern Ireland:
Harold Caccia
For the United States of America:
Herman Phleger
Paul C. Daniels

Whereas the Senate of the United States of America by their resolution of August 10, 1960, two-thirds of the Senators present concurring therein, did advise and consent to the ratification of the said Treaty;

Whereas the said Treaty was duly ratified by the President of the United States of America on August 18, 1960, in pursuance of the aforesaid advice and consent of the Senate;

Whereas it is provided in Article XIII of the said Treaty that upon the deposit of instruments of ratification by all the signatory States, the said Treaty shall enter into force for those States and for States which have deposited instruments of accession;

Whereas instruments of ratification were deposited with the Government of the United States of America on May 31, 1960 by the United Kingdom of Great Britain and Northern Ireland; on June 21, 1960 by the Union of South Africa; on July 26, 1960 by Belgium; on August 4, 1960 by Japan; on August 18, 1960 by the United States of America; on August 24, 1960 by Norway; on September 16, 1960 by the French Republic; on November 1. 1960 by New Zealand; on November 2, 1960 by the Union of Soviet Socialist Republics; and on June 23, 1961 by Argentina, Australia, and Chile; and an instrument of accession was deposited with the Government of the United States of America on June 8, 1961 by the Polish People's Republic;

And whereas, pursuant to the aforesaid provision of Article XIII of the said Treaty, the Treaty entered into force on June 23, 1961;

Now, therefore, be it known that I, John F. Kennedy, President of the United States of America, do hereby proclaim and make public

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the Antarctic Treaty to the end that the same and every article and clause thereof shall be observed and fulfilled with good faith, on and after June 23, 1961 by the United States of America and by the citizens of the United States of America and all other persons subject to the jurisdiction thereof.

In testimony whereof, I have caused the Seal of the United States of America to be hereunto affixed.

Done at the city of Washington this twenty-third day of June in the year of our Lord one thousand nine hundred sixty-one and of the Independence of the United States of America the one hundred eighty-fifth.
[SEAL]

John F. Kennedy.

By the President:
Dean Rusk, *Secretary of State.*

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